Fishery Data Series No. 17-15

Afognak Lake Sockeye Salmon Stock Monitoring, 2016

by

Darin Ruhl

August 2017

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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AFOGNAK LAKE SOCKEYE SALMON STOCK MONITORING, 2016

by
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ABSTRACT

Concerns expressed by local subsistence users over declines in Afognak Lake sockeye salmon *Oncorhynchus nerka* production prompted the Alaska Department of Fish and Game to investigate Afognak Lake's rearing environment beginning in 2003. Funded through the U.S. Fish and Wildlife Service Office of Subsistence Management, Alaska Sustainable Salmon Fund, and Kodiak Regional Aquaculture Association, this report provides results from the 2016 season.

Based on established mark–recapture techniques, an estimated 227,178 sockeye salmon smolt outmigrated from Afognak Lake in 2016. From 2003-2015, the outmigration averaged 319,205 and ranged from 127,861 to 564,793 smolt. Age-1 smolt made up 93.6% of the outmigration in 2016 and averaged 76.9% of the outmigration from 2003 to 2015. Length, weight, and condition data indicate fairly healthy, robust Age-1 smolt over the 14 years of the project with an average condition factor of 0.81.

Limnological sampling was conducted during 5 monthly events from May to September in 2016. Phosphorus concentrations and zooplankton densities remained low, while chlorophyll-*a* levels were slightly above average. Nitrogen concentrations, lake temperatures, and phytoplankton biovolume were above average for the third consecutive year.

Afognak Lake sockeye salmon returned in sufficient numbers to meet the escapement goal of 20,000–50,000 sockeye salmon while supporting subsistence, sport, and commercial harvests. The escapement of 33,167 fish in 2016 was slightly below the average of 41,479 sockeye salmon (2011–2015) and was predominately composed of age-1.3 and age-1.2 fish.

Key words: Afognak Lake, Litnik, mark-recapture, outmigration, escapement, Kodiak Island, *Oncorhynchus nerka*, smolt, sockeye salmon, subsistence harvest, inclined plane trap, zooplankton

INTRODUCTION

The Afognak Lake (also referred to as "Litnik" by local residents) watershed is located on the southeast side of Afognak Island, approximately 45 km northwest of the city of Kodiak (Figure 1). Afognak Lake (58°07′ N, 152°55′ W) lies 21.0 m above sea level, is 8.8 km long, and has a maximum width of 0.8 km (Schrof et al. 2000; White et al. 1990). The lake has a mean depth of 9.2 m, a maximum depth of 26.0 m, a total volume of 44.6 x 10^6 m^3, and a surface area of 5.5 km^2 (Figure 2). The shallow nature of Afognak Lake and a watershed area of 90 km^2 result in a very short lake-water residence time of 0.4 years. Afognak Lake drains in an easterly direction into the 3.2 km long Litnik River, which in turn flows into Afognak Bay. Afognak Bay is part of the Alaska Maritime National Wildlife Refuge and is where most localized subsistence sockeye salmon (*Oncorhynchus nerka*) fishing occurs. The Afognak Native Corporation owns the land surrounding the Afognak Lake watershed down to tidewater.

A counting weir for adult salmon was first established on Afognak River in 1921 just below the lake outlet and was operated intermittently through 1977. From 1978 to the present, the weir has been consistently operated. In 1986, the weir was relocated to its current location, approximately 200 meters upstream of the Afognak River mouth. The Alaska Department of Fish and Game (ADF&G) has conducted annual weir counts in conjunction with sockeye salmon age, sex, and length (ASL) sampling at the current site. Catch data has been documented through the ADF&G commercial landing fish ticket system, statewide sport fish surveys, and subsistence fishing permits since the late 1970s (Anderson et al. 2016).

In response to declining adult returns, in 1987, ADF&G, in cooperation with the Kodiak Regional Aquaculture Association (KRAA), initiated pre-fertilization fisheries and limnological investigations at Afognak Lake (Honnold and Schrof 2001; Schrof et al. 2000; White et al. 1990). Results of these investigations indicated that sockeye salmon production was limited by rearing capacity (White et al. 1990). Nutrient enrichment was recommended and implemented in 1990 with the intention to increase sockeye salmon rearing capacity in the lake. ADF&G and KRAA jointly fertilized Afognak Lake for 11 years (1990–2000) and stocked a total of 2,054,000 sockeye (1,530,500 million fingerling and 523,500 pre-smolt) in 1992, 1994, and 1996 through 1998 (Schrof et al. 2000).

Afognak Lake sockeye salmon runs substantially declined once fertilization and stocking were discontinued (Appendix A14; 2001), and escapements from 2001 through 2007 were below the sustainable escapement goal (SEG) range of 40,000 to 60,000 sockeye salmon (Anderson et al. 2014; Baer 2011; Honnold et al. 2007; Nemeth et al. 2010). As a result of these sockeye salmon poor runs, the commercial, subsistence, and sport fisheries in the Southeast Afognak Section (Figure 1), which includes all of Afognak Bay and surrounding waters, were closed or restricted from 2001 until 2005 and again in 2007.

In 2004, new sustainable salmon management policies, 5 ACC 39.222 and 5 ACC 39.223, provided the framework for a team of ADF&G biologists to re-evaluate the existing Afognak Lake sockeye salmon escapement goal. The team recommended changing the escapement goal from an SEG of 40,000 to 60,000 sockeye salmon to a biological escapement goal (BEG) of 20,000 to 50,000 sockeye salmon (Nelson et al. 2005). The recommendation was based on analysis of a Ricker spawner-recruit model and limnological data, excluding data from years in which the lake was fertilized. In 2007 and 2010, the escapement goal was re-evaluated with additional years of data and was recommended to remain unchanged (Honnold et al. 2007; Nemeth et al. 2010).

Escapements during the last 15 years have been just below (2002 and 2004) to just above (2001, 2003, 2005–2008) the lower bound of the BEG (Appendix A14). Since 2008, the Afognak River sockeye salmon run has been within the lower and upper escapement goal (20,000–50,000) and has supported commercial and subsistence harvests.

In addition to sockeye salmon, other fish species in the Afognak Lake drainage include pink salmon *O. gorbuscha*, coho salmon *O. kisutch*, rainbow trout (anadromous and potamodromous) *O. mykiss*, Dolly Varden *Salvelinus malma*, threespine stickleback *Gasterosteus aculeatus*, and coastrange sculpin *Cottus aleuticus* (White et al. 1990). Chinook *O. tshawytscha* and chum *O. keta* salmon have been observed in the Afognak River on occasion but have not established discernible spawning populations (White et. al 1990).

Afognak Lake sockeye salmon are an important target species for salmon fisheries within the Kodiak region. Residents of Port Lions, Ouzinkie, Afognak Village, and Kodiak have traditionally harvested salmon in Afognak Bay for subsistence uses (Figure 1). Local subsistence users, represented by the Kodiak-Aleutians Regional Advisory Council, Kodiak Fish and Game Advisory Committee, and Kodiak Tribal Council, contended that continued closures of the Afognak system would make it more difficult for local residents to harvest sockeye salmon and would shift fishing effort to small nearby sockeye salmon runs and the Buskin River. In 2003, ADF&G received funding through the Office of Subsistence Management's (OSM) Fishery Resources Monitoring Program to determine the feasibility of estimating sockeye salmon smolt production coming out of Afognak Lake and identify changes in the freshwater rearing environment before they were realized in adult returns. The 2003 study showed that sockeye salmon smolt could be effectively trapped in Afognak River and their abundance reliably estimated using mark–recapture techniques (Honnold and Schrof 2004).

Continued analysis of Afognak Lake and annual smolt emigration studies were deemed of high importance to evaluate the growth and production of juvenile sockeye salmon. Recognizing the importance of continued studies on Afognak Lake sockeye salmon production, OSM granted funding since 2003 to ADF&G for smolt and limnological studies. Alaska Sustainable Salmon Fund (AKSSF) provided funding for adult enumeration from 2014 through 2015, and the Kodiak Regional Aquaculture Association provided funding for the 2016 adult enumeration.

Data collected from this project have enabled researchers to better identify factors specifically affecting and controlling sockeye salmon production within the freshwater environment. This information continues to help refine the escapement goal and improve preseason run forecasts to allow for maximum sustainable yield and prevent unnecessary restrictions of federal and state subsistence fisheries.

PROJECT OBJECTIVES

Smolt

1. Estimate the abundance of outmigrating sockeye salmon smolt within 25% (relative error) of the true value with 95% confidence using mark-recapture techniques.
2. Estimate the age composition of outmigrating sockeye salmon smolt within $d = 0.05$ (size of the effect) of the true proportion (for each major age group within each stratum) with 95% confidence.
3. Estimate the average length (mm), weight (g), and Fulton's condition factor (K) by smolt age group and stratum.

Adult salmon

4. Enumerate the escapement of adult sockeye salmon returns through the weir and into Afognak Lake.
5. Estimate the age and sex composition of adult sockeye salmon returns where estimates are within $d = 0.07$ of the true proportion (for each age group within each statistical week) with 95% confidence.
6. Estimate the average length (mm) of adult sockeye salmon by age and sex.

METHODS

SMOLT TRAPPING AND POPULATION ESTIMATION

Trap Deployment and Assembly

An inclined plane trap (Ginetz 1977; Todd 1994) was installed on 2 May approximately 32 m upstream from the adult salmon weir site (Figure 3). The smolt trap was positioned close to the thalweg of the river, where water velocity was great enough to reduce trap avoidance and capture a representative portion of the outmigrating smolt. The smolt trap was positioned roughly three meters downstream of the historic site to accommodate wing additions and trap modifications during low water conditions. A live box (1.2 m x 1.2 m x 0.5 m) was attached to the outlet of the inclined plane trap, and the mouth of the trap was connected to cables attached to hand-powered cable winches ("come-alongs") fixed to each streambank. Perforated (3.2 mm) aluminum sheeting (1.2 m x 2.4 m) supported by a Rackmaster[1] pipe frame was placed at the entrance of

[1] Product names are included for completeness but do not constitute endorsement.

the trap in a “V” configuration to divert water and smolt into the mouth of the inclined plane trap (Figure 3). The trap was secured to an aluminum pipe frame, which allowed the back end of the trap and live box to be adjusted vertically in response to water level fluctuations. Detailed methods of trap installation, operation, and maintenance are described in the 2016 Afognak Lake Operational Plan (Thomsen and Estrada 2014).

Smolt Capture and Handling

Smolt were captured in the trapping system and held in the attached live box until they were counted. During the night (2200 to 0800 hours) the live box was checked every 1 to 2 hours, depending on the outmigration magnitude. During the day (0801 to 2159 hours), the live box was checked every 3 to 4 hours. All smolt were removed from the live boxes with a dip net, identified, enumerated, and either released downstream of the trap or transferred to an instream holding box for sampling or marking. Species identification was made by visual examination of external characteristics of juvenile salmonids (Pollard et al. 1997). All data, including mortality counts, were entered on a reporting form each time the trap was checked. Smolt trapping operations were concluded when daily smolt counts were less than 100 smolt per day for 3 consecutive days.

Population Estimation

Total smolt abundance was estimated using single-site mark-recapture trials to estimate trap efficiency within specific recapture periods (strata), generally weekly, when smolt numbers were sufficient (Carlson et al. 1998). Trap efficiencies were adjusted to reflect delayed mortality (described below) and used to estimate the number of smolt outmigrating from the watershed during each stratum.

Releases of sockeye salmon smolt marked with Bismarck Brown Y dye were made once per strata (weekly), as well as when changes were made to the trapping system, when stream stage height increased or decreased dramatically, or a low abundance of smolt prevented achievement of the desired sample size. As in previous years at Afognak Lake, an effort was made to achieve trap efficiencies between 15% and 20% (Thomsen and Richardson 2013). To estimate total smolt abundance for each strata with a 5% probability of exceeding a relative error (RE) of 25%, a minimum of 330 smolt were marked and released for each experiment (Carlson et al. 1998). To estimate mortality associated with the marking, holding, and transport process, 50 marked and 50 unmarked fish were retained after transport to the release site and monitored for 3 days after the release of dyed fish. Therefore, a minimum sample size of 430 was targeted as the goal for each experiment to account for mortality and testing. Actual numbers of fish marked, released, and retained for mortality testing varied by release event (Tables 1 and 2).

Several assumptions need to be made to produce a robust smolt mark–recapture estimate. These assumptions are listed below and described further in Carlson et al. (1998):

- the smolt population was unchanging (i.e., smolt are outmigrating and do not migrate back above the capture location),
- all smolt had the same probability of being marked (i.e., trap is not selective and strata are consistent),
- all smolt had the same probability of capture (i.e., marking fish does not affect their behavior or ability to be captured),
- all marked smolt released can be recovered (i.e., marking mortality was accurate),

- all marked smolt were identifiable (i.e., crew well trained and strata are discrete),
- marks were not lost after marking (i.e., effectively dyed for external verification),
- complete mixing of marked smolt and other migrating salmon occurred after release (i.e., released at onset of the nightly smolt migration far enough above the capture location to promote complete mixing).

Trap efficiency (E_h) for stratum h was calculated as

$$E_h = \frac{m_h + 1}{M_h + 1}, \tag{1}$$

where

M_h	=	number of marked smolt released in stratum h
		(Note: M_h is adjusted for marking and holding mortality)
m_h	=	number of marked smolt recaptured in stratum h.

A modification of the stratified Petersen estimator (Carlson et al. 1998) was used to estimate the number of unmarked smolt U_h emigrating within each stratum h as

$$\hat{U}_h = \frac{u_h (M_h + 1)}{m_h + 1}, \tag{2}$$

where

u_h	=	number of unmarked smolt recaptured in stratum h.

Variance of the smolt abundance estimate was estimated as

$$v\left(\hat{U}_h\right) = \frac{(M_h + 1)(u_h + m_h + 1)(M_h - m_h)u_h}{(m_h + 1)^2 (m_h + 2)}. \tag{3}$$

Total abundance of N of unmarked smolt over all strata was estimated by

$$\hat{U} = \sum_{h=1}^{L} \hat{U}_h, \tag{4}$$

where L is the number of strata. Variance for $\hat{U}$ was estimated by

$$v\left(\hat{U}\right) = \sum_{h=1}^{L} v\left(\hat{U}_h\right), \tag{5}$$

and 95% confidence intervals were estimated using

$$\hat{U} \pm 1.96\sqrt{v\left(\hat{U}\right)}, \tag{6}$$

which assumes that N is approximately normally distributed.

Within each stratum h, the total population size by age class j was estimated as

$$\hat{U}_{jh} = \hat{U}_h \hat{\theta}_{jh}, \tag{7}$$

where $\hat{\theta}_{jh}$ is the observed proportion of age class j in stratum h. Variance of $\hat{\theta}_{jh}$ was estimated using the standard variance estimate of a population proportion (Thompson 1987). The variance of $\hat{U}_{jh}$ was then estimated by

$$v\left(\hat{U}_{jh}\right) = \hat{U}_h^{\,2}\, v\left(\hat{\theta}_{jh}\right) + \hat{U}_h\, v\left(\hat{\theta}_{jh}\right)^2. \tag{8}$$

The total number of emigrating smolt within each age class was estimated by summing the individual strata estimates, and its variance was likewise estimated by summation over the individual strata estimates.

Dyeing Procedure

In 2016, minor modifications to the dyeing procedure significantly reduced smolt mortalities and will be incorporated in future project operational plans. The dyeing procedure revisions will be further examined in the Discussion section. Dissolved oxygen and temperature levels were maintained at ambient river levels and continuously monitored and recorded throughout the entire dyeing procedure.

1. Collected smolt were placed in a secured 32-gallon lidded trash can filled with river water in the bed of a side by side all-terrain vehicle.
2. Smolt were given 30 minutes to rest and recover before the addition of the dye.
3. Prior to adding the dye, 50 smolt (undyed) were randomly selected and placed in a separate holding box for transport to the release site.
4. Sockeye salmon smolt were dyed in a solution of 3.4 grams of Bismarck Brown Y dye in 30 gallons of river water (~30 mg/L solution) for 15 minutes. Dyed smolt that displayed unusual behavior (labored respiration, flared gills, side swimming, etc.) were tallied, removed from the experiment, and released downstream of the recapture site.
5. The dye solution was flushed with river water using a small water pump for 90 minutes or until the water was clear.
6. A 0.25% sodium bicarbonate solution, to maintain a stable pH, and non-iodized salt was added to the transport river water to achieve a 0.75% solution to replicate physiological levels and reduce metabolic stress and electrolyte depletion that can cause transport mortality. Smolt were transported slowly (~2 mph) in the bed of a side-by-side all-terrain vehicle to the release site.
7. Following transport to the release site, smolt were held for a minimum of 90 minutes to assess condition, remove dead individuals, and minimize stress before release.
8. A total of 50 dyed smolt were randomly selected and placed in a separate instream holding box from the 50 undyed smolt for 3 days to estimate delayed mortality resulting from the marking, holding, and transport process. The proportion of smolt (dyed minus undyed) that expired during the 3-day holding period was used to estimate the actual number of marked smolt available for recapture in the experiment (M_h). M_h was adjusted by multiplying the delayed mortality ratio (total number of marked and held divided by total number of marked dead) by the number of dyed smolt released.

9. Dyed smolt that did not display unusual behavior were placed in 5-gallon buckets for release. Timing of the dyeing process was started so dyed smolt (>330) were released evenly across the width of the stream at 2300 hours.

All dyed smolt recaptured at the downstream trap site were counted and assigned to the strata corresponding to the time period starting the day of their release until the day before the next release and mark–recapture event.

Age, Weight, and Length Sampling

To ensure proportional abundance sampling, approximately 4% of the daily sockeye salmon smolt catch was sampled to obtain age, weight, and length (AWL) data. For every 100 sockeye salmon smolt counted out of the trap, the field crew retained 4 smolt for AWL sampling the following morning. Sampling days occurred for a 24-hour period from noon to noon and were identified by the date of the first noon-to-midnight period. Traps were checked more frequently throughout the evening during periods of increased smolt outmigration. Smolt were collected throughout the night and held in an instream live box. The following day, all smolt in the live box were anesthetized using tricaine methanesulfonate (MS-222) prior to being sampled. After being sampled, all smolt were held in aerated buckets of river water until they recovered from the anesthetic and subsequently released downstream from the trap.

Scales were removed from the preferred area of each sampled fish following procedures outlined by the International North Pacific Fisheries Commission (INPFC 1963) and mounted on a microscope slide for age determination. Age was estimated from scales viewed with a microfiche reader at 60X magnification and recorded in European notation (Koo 1962) following the criteria established by Mosher (1968). Fork length (L) was recorded to the nearest 1 mm and weight (W) to the nearest 0.1 g. In addition, the overall health or condition factor of each sampled smolt was assessed by calculating its body condition factor (*K*; Bagenal and Tesch 1978) as

$$K = \frac{W}{L^3}10^5 \quad . \tag{9}$$

ADULT SALMON ASSESSMENT

Weir Installation and Adult Salmon Enumeration

A 27 m long weir was installed perpendicular to the stream flow and consisted of 10 wooden tripods (each tripod consisting of three 4″ x 6″ x 8′ spruce timbers and 2″ x 6″ x 6′ horizontal cat-walk supports), 33 aluminum pipes (2″ x 10′), 44 picketed aluminum panels (1″ aluminum pipe with 1″ spacing totaling 30″ x 6′), and 2 framed panel gates (Figure 4). All materials were secured with sand bags and zip-ties to create a fish-tight structure that conformed to the contour of the stream channel.

Two counting gates were placed between panels in the two deepest channels of the river enabling fish to be counted as they passed through the weir. A white flash panel was placed on the substrate beneath each gate to enhance visibility and species identification. Fish were counted every day by trained field technicians using hand tally denominators as fish migrated upstream through the gates. The counting gates remained closed until staff were present to count fish through the weir for escapement enumeration or when fish were being collected into the live trap for age, sex, and length sampling (ASL; Thomsen and Estrada, 2014).

Age, Sex, and Length Sampling

An upstream "Scott live trap" (local name for a modified trap capable of capturing steelhead; Figure 4) was installed in front of the east-bank gate, which acted as a sampling trap as well as a downstream steelhead trap. The trap consisted of 6 weir panels placed horizontally in the river in the form of a diamond with two exit gates, one near the weir and the second at the upstream end of the trap (Thomsen and Estrada 2014).

Escaping adult sockeye salmon were sampled at the weir site throughout the run. Details and procedures for adult sampling are outlined in the *Kodiak Management Area Sockeye Salmon Catch and Escapement Sampling Operational Plan* (Wattum and Foster 2016). All scales, when possible, were collected from the preferred area of each fish (INPFC 1963). Scales were mounted on scale "gum" cards and returned to the Kodiak ADF&G office where impressions were made on cellulose acetate (Clutter and Whitesel 1956). Fish ages were determined by examining scale impressions for annual growth increments using a microfiche reader fitted with a 60X lens following designation criteria established by Mosher (1968). Ages were recorded using European notation (Koo 1962), where a decimal separates the number of winters spent in fresh water (after emergence) from the number of winters spent in salt water (e.g., 2.3). The total age of the fish includes an additional year representing the time between egg deposition and emergence of fry. Length measurements were taken from mid eye to tail fork (METF) to the nearest 1 mm, and sex was determined from external morphological characteristics.

Age and sex composition of the upstream migrating adult sockeye salmon were estimated as a group of proportions (p_{ij}) characterizing a multinomial distribution:

$$\hat{p}_{ij} = n_{ij} / n, \tag{10}$$

where

n = number in the sample

n_{ij} = number in the sample of age i and sex j.

On days when escapement occurred but no samples were collected, proportions were estimated by linear interpolation between sampling events. The sample size was selected so that the proportion of each major age group (by statistical week) was estimated within at least $\alpha = 0.07$ of its true value 95% of the time (Thompson 1987). Standard error of the age proportions was calculated as the square root of estimated variance of a proportion (Thompson 1987).

LIMNOLOGICAL ASSESSMENT

Lake Sampling Protocol

Five limnological surveys of Afognak Lake were conducted at approximately 4-week intervals from May to September 2016. Two stations, marked with anchored mooring buoys and located with Global Positioning System (GPS) equipment, were sampled from a float plane during each survey (Figure 2). Zooplankton samples were collected at both stations, but water samples were only collected at Station 1. Data and water samples were returned to the ADF&G Kodiak Island Limnology Laboratory (KILL; Kodiak, AK) for analyses.

Temperature, Dissolved Oxygen, Light, Water Clarity, and Euphotic Volume

Water temperature (°C) and dissolved oxygen (mg/L) levels were measured with a YSI ProODO meter. Surface temperature readings were confirmed with a YSI 60 pH/temperature meter. Temperature and dissolved oxygen readings were recorded at half-meter intervals to a depth of 5 m and then at 1 m intervals to the lake bottom.

Water transparency was measured at each station using a Secchi disc as described in Ruhl (2013). Measurements of light in the visible spectrum range (400–700 nm), known as photosynthetic active radiation (PAR), were obtained with a Li-Cor Li-250 submersible photometer at the lake sampling stations during the monthly sampling events. Readings were taken just below the water's surface (subsurface) at half-meter intervals below the water surface until reaching a depth of 5 m, and at 1 m intervals to the lake bottom or to a depth at which the reading was less than 1% of the subsurface reading. Measurements were adjusted by linear regression to the Beer–Lambert equation (Wetzel 1983) to estimate an integrated vertical extinction coefficient (K_d m) for PAR within the euphotic zone, the layer of water from the surface down to 1% of subsurface PAR as

$$K_d \text{ m} = (1/z) \ln (I_z / I_o), \tag{11}$$

where

I_o = light intensity just below the water surface, and

I_z = light intensity at water depth z in meters.

Lake primary production potential for rearing juvenile sockeye salmon was assessed through a euphotic volume calculation as the product of the average euphotic zone depth (EZD) for the 5 monthly sampling periods and lake surface area (Koenings and Burkett 1987).

General Water Chemistry, Photosynthetic Pigments, and Nutrients

During each survey, water samples were collected at a depth of 1 m below the water's surface using a 4.0 L Van Dorn sampler. Each water sample was collected in a pre-cleaned polyethylene carboy after being rinsed with sample water, kept cool and dark in transport, and refrigerated at the KILL. Water samples were processed or frozen within 12 hours of arriving at the laboratory. Lake water from the carboy was transferred into a sample rinsed 500 mL bottle, refrigerated, and analyzed for alkalinity and pH. Two 250 mL bottles were also rinsed with sample water and filled with unfiltered water from the carboy, frozen, and later analyzed for total Kjeldahl nitrogen (TKN), total phosphorus (TP), and reactive silicon (Si). A total of 2 L of water was filtered using 2 different methods for assessing different water quality parameters. The first 1 L sample of lake water was filtered into an Elenmeyer flask through a rinsed, pre-combusted 47 mm diameter Whatman GF/F glass micro fiber filter under 4 psi vacuum pressure to isolate the filtrate. The filtrate was then analyzed for total filterable phosphorus (TFP), filterable reactive phosphorus (FRP), nitrate + nitrite (NO_3^- + NO_2^-; N+N), and ammonia (NH_4^+; TA). The second 1 L sample of lake water was filtered through another Whatman GF/F filter pad (<4 psi), and approximately 5 mL of magnesium carbonate ($MgCO_3$) was added near the end of the filtration process to act as a preservative. The filtrate was discarded and the fiber filter was retained and frozen on a petri dish for chlorophyll-*a* (chl-*a*) and phaeophytin (phaeo-*a*) analysis.

The pH of water samples from samples collected at 1 m was measured in situ with a YSI 60 pH meter. Alkalinity (mg/L as $CaCO_3$) was determined from 100 mL of unfiltered water titrated with 0.02 N H_2SO^4 to a pH of 4.5 using a Mettler Toledo FE20 (FiveEasy 20) meter.

TA, N+N, Si, and FRP were analyzed using a SEAL Analytical AA3 segmented flow following the manufacturer's chemistry protocols described in Ruhl (2013). TP and TFP were analyzed using digestion methods and autoanalyzer methods described in Ruhl (2013). TKN was determined at the University of Georgia Feed and Environmental Water Laboratory using the 4500-N D conductimetric method of TKN determination. Total nitrogen (TN), the sum of TKN and N+N, and the ratio of TN to TP were calculated for each sample.

Chlorophyll *a* is the primary photosynthetic pigment in plants and is commonly used as an index of phytoplankton abundance. Samples of chl *a* were prepared for analysis by grinding each frozen particulates filter in 90% buffered acetone into a paste-like slurry in separate 15 mL glass centrifuge tubes. Each sample was stored in the freezer for 22-24 hours to optimize pigment extraction. Pigment extracts were diluted to a final volume of 12 mL with 90% acetone, centrifuged, and decanted. The extracts were analyzed with a Genesys 10S (spectrophotometer) using methods described in Ruhl (2013). Concentrations of phaeo *a*, a degradation product of chl *a*, were simultaneously estimated during the spectrophotometer analysis of chl *a* by acidifying 3 mL of extract with 0.025 mL 2N HCl.

Zooplankton

Vertical zooplankton hauls were made at each station using a 0.2 m diameter conical net with 153 µm mesh. The net was pulled manually at a constant speed (~0.5 m/second) from approximately 1 m off the lake bottom to the surface. The contents from each tow were emptied into a 125 mL polyethylene bottle and preserved in 10% buffered formalin. Cladocerans and copepods were identified to genus using taxonomic keys in Edmondson (1959), Thorp and Covich (2001), and Wetzel (1983). Zooplankton lengths were measured in triplicate 1 mL subsamples taken with a Hansen-Stempel pipette and placed in a Sedgewick-Rafter counting chamber. Zooplankton were grouped at the genus level and measured to the nearest 0.01 mm. The standard deviation (SD) of the lengths (L) of up to 15 individuals was estimated. This value was then used to estimate the appropriate sample size (*n*) by applying it to a *t*-test (t) with a 0.05 significance level and relative to 10% variation from the mean measured length calculated as

$$n = [(t \times SD)/(0.1 \times L)]^2. \quad (12)$$

Biomass was estimated from species-specific linear regression equations of wet length and dry weight derived by Koenings et al. (1987). For each survey, average density and biomass from the two stations were calculated for each genera.

Phytoplankton

For phytoplankton analysis, 100 mL was subsampled from 1 m water sample carboy and preserved by adding 2 mL of Lugol's acetate. Samples were sent to BSA Environmental Services Incorporated (Beachwood, Ohio) for species composition and biovolume (μm^3/L).

RESULTS

SMOLT MIGRATIONS

Smolt Capture

The trap was fished from 2 May until it was removed for the season on 23 June (53 days; Figures 5 and 6). Low water conditions rendered the trap inoperable in determining daily smolt counts from from 27 May to 31 May. In an attempt to estimate outmigrating smolt during this time period, a time series regression analysis was performed to calculate the total number of smolt that would have been captured when the trap was not fishing. The time series analysis increased the trap catch by 8,238 fish for a season total of 38,525 sockeye salmon smolt that were captured in the inclined plane trap (Tables 1 and 2). In addition to sockeye salmon smolt, there were 2,212 juvenile coho salmon, 1,370 Dolly Varden, 247 stickleback, 187 sculpin, 32 rainbow trout, and nine eulachons captured.

The average number of smolt captured in the downstream inclined plane trap from 2003 to 2015 was 47,276 sockeye salmon; ranging from 19,686 in 2015 to 82,970 in 2003 (Appendix A1).

Trap Efficiency

Six trap efficiency tests conducted during the smolt run ranged from 8.9% in Stratum 5 (7 June–14 June) to 29.3% in Stratum 4 (1 June–6 June; Tables 1 and 2; Figure 6). In 2016, mean estimated trap efficiency was 16.5% (2003–2015 at 16.1%; 2011–2015 at 14.9%; Table 1; Appendix A1).

Magnitude and Timing

An estimated 227,178 sockeye salmon smolt outmigrated from Afognak Lake in 2016 (95% confidence interval 172,650–281,706 fish; Table 1). Peak smolt outmigration occurred 2 June to 5 June, with the outmigration tapering off shortly thereafter (Table 2).

Age, Weight, Length, and Condition Factor

AWL data were obtained from 1,209 sockeye salmon smolt collected proportionally throughout the trapping period (Table 3). Summing smolt abundance estimates by age class for all 6 mark-recapture strata resulted in 212,628 (93.6%) age-1, and 14,550 (6.4%) age-2 smolt outmigrating to the ocean (Table 4; Figure 8). The proportion of age-1 fish was greater than the 5-year and 13-year averages for age-1 sockeye salmon smolt (2011–2015, 76.5%; 2003–2015, 76.9%) but less than the proportion of age-2 smolt (2011–2015, 23.5%; 2003–2015, 23.1%; Appendix A2).

Age-1 sockeye salmon smolt had a mean weight of 3.0 g, a mean length of 72.1 mm, and a mean K of 0.81. Sampled age-2 sockeye salmon smolt had a mean weight of 3.6 g, a mean length of 78.3 mm, and a mean K of 0.74 (Figure 9; Appendix A3). No age-3 sockeye salmon smolt were sampled in 2016.

ADULT SALMON ASSESSMENT

Enumeration

The first adult sockeye salmon passed through the counting gates on 11 May. Adult salmon were enumerated on a daily basis until 27 July when the weir was removed with 33,167 sockeye, 6 chum, and 4 coho salmon escaping into the Afognak system (Figure 12; Appendix A5). Sockeye salmon escapement peaked between 29 May and 7 June, when 14,717 fish were enumerated (Figure 11). Additionally, 11 steelhead kelts were passed downstream through the weir. The 2016 sockeye salmon escapement count was below the 5-year and 10-year average (Appendix A5). However, coho salmon escapement enumeration is highly dependent on the date the weir is removed (Table 15), which will be further examined in the Discussion section.

Age, Sex, and Length Data

A total of 1,928 adult sockeye salmon were sampled from 11 May through 26 July, resulting in a total of 1,772 samples with ageable scales (Table 7). The goal of estimating age composition of the escapement within d = 0.07 (95%) confidence was achieved for all ages within each stratum.

The majority (57.6%) of the sockeye salmon escapement was composed of age-1.3 fish, while 17.8% were age-2.3 fish, 11.6% were age-1.2 fish, and 10.9% were age-2.2 fish (Table 7; Appendix A4). The majority of age-1.2 escaped during June and early July and the majority of age-1.3 fish escaped during late May to early June. The estimated sex composition of the escapement was 59.6% female and 40.4% male. Overall average length was 509 mm for all sockeye salmon (Table 7). The Afognak Lake sockeye salmon escapement is typically composed of ocean-age-3 fish, followed by ocean-age-2 fish (Appendix A4; Figure 13).

Commercial and Subsistence Harvest

A total of 7,563 sockeye salmon were commercially harvested by 12 permit holders from the Afognak Bay portion of the Southeast Afognak Section (252-34) in 2016 (Table 5; Figure 12). In addition, a total of 1 Chinook, 74 chum, 59 coho, and 765 pink salmon were commercially harvested from that portion of the Southeast Afognak Section (Anderson et al. 2016). The most recent 5-year average sockeye salmon commercial harvest from the Afognak Bay portion of the Southeast Afognak Section totaled 7,515 (Table 5; Figure 12).

A total of 3,275 sockeye were harvested for subsistence by 90 permit holders from the Afognak Bay portion of the Southeast Afognak Section (252-34) in 2016 (Table 5; Figure 12). In addition, a total of 4 Chinook, 201 coho, and 57 pink salmon were harvested for subsistence from that portion of the Southeast Afognak Section. The most recent 5-year average sockeye salmon subsistence harvest from the Afognak Bay portion of the Southeast Afognak Section totaled 2,123 sockeye salmon.

LIMNOLOGICAL ASSESSMENT

Physical Data

Monthly water temperatures at Station 1 taken during limnological sampling ranged from 9.0°C near the lake bottom on 16 May to 17.7°C near the surface on 12 July (Figure 10). Seasonal mean water temperatures at 1 meter were above historical averages (1989–2015 and 2011–2015; Appendix A6). Mean 1 m temperatures were 13.3°C in the spring, 17.6°C in the summer, and 16.7°C in the fall (Appendix A6).

In 2016, the data logger at 1 meter (Station 2) was operated continuously from 15 May to 21 September, recording temperature every hour (Table 8). The temperature logger recorded a maximum of 21.8°C in August, a minimum of 9.8°C in May, and an overall mean of 16.0°C. Average summer 1 m temperatures recorded by the data logger were greater in 2016 than previous years (2010–2015; Table 8).

Afognak Lake was stratified in June and July with mixing occurring in May and August–September (Figure 10). Monthly dissolved oxygen (DO) concentrations at Station 1 ranged from 8.2 mg/L at the bottom in the summer to 11.4 mg/L near the lake surface in the spring (Appendix A7). Mean vertical light extinction coefficient was -0.60 meters, mean EZD depth was 7.41 meters, and mean Secchi disk reading was 4.15 meters (Appendix A8). The estimated euphotic volume (EV) for Afognak Lake was 39.27×10^6 m^3 (Appendix A8). Using the EV model and 800–900 spawners per EV unit resulted in a spawning capacity estimate of 31,431 to 35,360 adults (Koenings and Kyle 1997; Appendix A8).

EZD values recorded in 2016 indicated that, on average, the first 7.4 meters of the water column at the sampling stations were photosynthetically active (Appendix A8). Historical mean EZD values were greater, with an average of 9.3 meters of the water column being photosynthetically active (1987–2015; Appendix A8).

Water Chemistry and Nutrients

All nutrient and photosynthetic concentrations that are analyzed from Afognak Lake are collected at Station 1 from a depth of 1 meter. Afognak Lake mean pH was 7.77 and ranged from 7.66 in June to 7.89 in August (Station 1; Table 9; Appendix A9). Mean alkalinity level was 10.2 mg/L and ranged from 8.5 mg/L in May and 12.5 mg/L in September (Table 9). Mean chl-*a* concentration was 1.92 μg/L and ranged from 1.60 μg/L in May and August to 2.24 μg/L in July and September (Table 9). Mean phaeo-*a* concentration was 0.95 μg/L and ranged from 0.45 μg/L in July to 1.54 μg/L in May.

Mean TP concentration was 4.4 μg/L and ranged from 3.4 μg/L in July to 5.7 μg/L in May (Table 10; Appendix A10). Mean TFP concentration was 1.8 μg/L and ranged from 1.4 μg/L in June to 2.1 μg/L in May and August. Mean FRP concentration was 1.4 μg/L and ranged from 1.2 μg/L in September to 1.7 μg/L in May. Mean reactive silicon concentration was 2,045.2 μg/L and ranged from 1,709.2 μg/L in September to 2,551.7 μg/L in July (Table 10).

Mean TKN concentration was 1,063.4 μg/L and ranged from 50.0 μg/L in September to 2,058.0 μg/L in July (Table 10; Appendix A10). August TKN was not analyzed. Mean NH_4^+ concentration was 8.1 μg/L and ranged from 2.1 μg/L in July to 13.1 μg/L in August. Mean NO_2 + NO_3 concentration was 29.5 μg/L and ranged from 10.8 μg/L in August to 68.3 μg/L in May. Mean TN concentration was 880.3 μg/L and mean TN to TP ratio, by weight, was 602.7:1.

Zooplankton

In 2016, overall (Stations 1 and 2 averaged) mean zooplankton density was 167,383 no/m^2 (Table 11). All zooplankton were cladocerans (Order Anomopoda and Ctenopoda) or copepods (Order Calanoida, Cyclopoida, and Harpacticoida). Cladocerans were more abundant (71.6% of mean density) than copepods (28.4%). Among the cladocerans, the 2 most abundant groups were *Bosmina* (78.9% of cladocerans; 56.5% of total) and *Holopedium* (4.8% of cladocerans; 3.5% of total). Other observed cladoceran genera were various unidentified immature cladocerans (10.1% of cladocerans; 7.2% of total) and *Daphnia l.* (.1% of cladocerans; .08% of total). Among the copepods, the 2 most abundant groups were *Epischura* (66.6% of copepods; 18.9% of total) and *Cyclops* (6.9% of copepods; 2.0 % of total).

In 2016, the seasonal mean weighted zooplankton biomass was 172.7 mg/m^2 and was mostly composed of the copepod genus *Epischura* (42.5%) and the cladoceran genus *Bosmina* (39.9%

of mean total biomass; Table 12). The remaining biomass was composed of *Holopedium* (6.6%), *Cyclops* (4.1%), *Daphnia l.* (3.4%), and *Diaptomus* (1.4%).

The copepod *Diaptomus* was the largest zooplankton taxa measured, with a weighted mean length of 0.83 mm (Table 13). Mean lengths of the remaining zooplankton, in decreasing size, were 0.79 mm for the copepod *Epischura*, 0.78 mm for the copepod *Cyclops*, 0.63 mm for the ovigorous cladoceran *Daphnia l.*, 0.56 mm for *Daphnia l.* and the ovigorous cladoceran *Holopediu*m, 0.49 mm for the cladoceran *Holopedium*, and 0.32 mm for the ovigorous cladoceran *Bosmina*.

Phytoplankton

In 2016, the seasonal mean phytoplankton biovolume was 599,699,142 μm^3/L, an increase of approximately 64% over last year. Phytoplankton species composition was predominately composed of Bacillariophyta (Diatoms; 28.8%; 172,762,113 μm^3/L) and Chlorophyta (Green algae; 138,809,642 μm^3/L; 23.1%; Table 14; Figure 16). From 2010 to 2016, total biovolume fluctuated tremendously, ranging from 654,787 μm^3/L in 2011 to 599,502,848 μm^3/L in 2016 (Appendix A16).

DISCUSSION

SMOLT ASSESSMENT

From 2003 through 2010, a single inclined plane smolt trap, located approximately 32 m upstream from the adult salmon weir site, was operated to capture outmigrating smolt, enumerate smolt, and recapture marked (dyed) fish, to ultimately estimate the population of smolt emigrating from Afognak Lake. From 2011 through 2015, two smolt traps were utilized with the primary trap deployed in the original location at the adult weir site and a second trap fished simultaneously approximately 1.2 km upstream from the adult salmon weir site solely to capture smolt for the dye test that measures the trap efficiency of the lower trap. The upstream trap was employed to address concerns that smolt were "predisposed" to capture in the lower trap because they were captured once before by the same trap, to decrease the number of times needed to handle the smolt, and to better understand factors leading to high mortality rates encountered during transportation of smolt from the downstream capture site to the upstream release site. Results from the two-trap method demonstrated that decreased transport distance reduced mortality, but over-handling during the dyeing process caused the majority of smolt mortality. In 2016, a single inclined-plane trap with minor revisions to the dyeing procedure was deemed adequate for capturing outmigrating smolt, enumerating smolt, and recapturing marked fish. Minor revisions consisted of decreasing the number of times smolt were handled during the dyeing procedure, increasing the rest time of dyed smolt before and after transport, and slowing down the vehicle transport speed to the upstream release site. These modifications to the dyeing procedure significantly reduced smolt mortalities and will be implemented in future smolt operations at Afognak Lake. Despite changes in field personnel, project biologists, trapping methods, and varying environmental conditions, a mean trap efficiency of 16.1% (2003–2015) has been within the targeted range of 15% to 20% and ranged from 11.4% to 19.9% annually (Appendix A1).

The Afognak Lake sockeye salmon smolt outmigration estimate (227,178) was just above the most recent five-year average since the mark–recapture project was initiated in 2003. It has been reported that salmon outmigrate earlier after a mild spring than a cold one (Burgner 1962), once lake temperatures rise above 4°C (Hartman et al. 1967) and a critical daylength is reached (Clarke and Hirano 1995). To determine if the smolt emigration was occurring while high water kept the primary trap from being installed, a secondary smolt trap was fished upstream from 30 April until the installment of the primary smolt trap on 2 May. A total of 17 sockeye smolts were captured by the secondary trap over those 3 days. Smolt operations for the 2016 season started on 2 May; 38 sockeye smolt were captured and the water temperature was 7°C (Table 2). Although the water temperature was above the 4°C, it is unlikely the outmigration was early because daily catches were low at both the secondary and primary trap at the beginning of trapping (Table 2).

Since the inception of the smolt project in 2003, high water events have typically occurred in the month of May and lower water conditions towards the middle of June. In 2016 this trend continued with high water events in early May and extremely low water conditions from late May through June, creating variable trapping conditions and configurations, yet targeted trap efficiencies (15% to 20%) were achieved (Tables 1 and 2).

The current trapping location has been utilized since 2003 and continues to be the preferred site because it has historically proven to capture a representative portion of the outmigrating smolt in variable stream conditions without major modifications. In 2016, trap modifications were made by adding perforated aluminum sheets fixed with clear plastic sheeting at the mouth of the trap to increase water flow (Figure 3). Despite these efforts throughout the trapping season, our confidence in the smolt estimate is poor and likely underestimated.

The outmigration timing was consistent with past years, with age-2 smolt outmigrating earlier than age-1 smolt (Figures 7 and 9). Age compositions were also comparable with past years (Appendix A2). Age-1 outmigrating smolt were larger in 2016 than the previous 5 years (2011–2015; Appendix A3). The continued preponderance and robust size of age-1 smolt typically indicates favorable freshwater rearing conditions (Koenings and Kyle 1997) or that rearing numbers are not exceeding the carrying capacity of the system; the extension of freshwater residence in sockeye salmon suggests decreased lake productivity or that the carrying capacity of the system is being taxed (Barnaby 1944; Burgner 1964; Koenings et al. 1993) . The relatively high K is probably a result of the low population size, reduced competition for resources, or increased productivity in the lake with a longer growing season as indicated by the warmer climatic conditions.

Zooplankton biomass and density estimates from limnological Station 1 (2001–2015) were low (71–173 mg/m^2; Appendix A11 and A12). The low average zooplankton densities, biomasses, and small *Bosmina* sizes indicate top-down pressure and competitive feeding conditions (Koenings and Kyle 1997; Appendix A11–A13), yet juvenile age-1 sockeye in 2016 had healthy condition, which generally indicates favorable rearing conditions. Examination of seasonal and ontogenetic variation in diets of juvenile sockeye salmon from 2010–2013 revealed that adult insects made up 74% of all sockeye salmon diets by weight and were present in 98% of all juvenile stomachs collected in Afognak Lake during the summer of 2013. Diets varied temporally for all fishes, but small sockeye salmon (<60 mm) showed a distinct shift in consumption from zooplankton in early summer to adult insects in late summer and a significant proportion of their nutritional needs are met by foraging for terrestrial and aquatic insects (Beaudreau and Finkle 2015; Richardson 2016; Thomsen and Richardson 2013).

It is possible that predation and competition by juvenile coho salmon in Afognak Lake may contribute to poor sockeye salmon egg to smolt survival. Ruggerone and Rogers (1992) found significant predation (up to 59% of sockeye salmon fry) by juvenile coho salmon on sockeye salmon fry in Chignik Lake. In 2013, juvenile coho salmon were collected from the shoals of Afognak Lake in May during the course of juvenile sockeye salmon sampling. The examination of juvenile coho salmon stomach contents confirmed predation on juvenile sockeye salmon during the juvenile lake assessment study (Thomsen and Richardson 2013). Of the 25 coho salmon stomachs examined, 22% had sockeye fry present, and 1 had 11 fry. More extensive sampling in terms of increased sample size and stations sampled should be considered in the future to determine the significance of juvenile coho salmon predation on lake-rearing sockeye salmon and their effects upon the smolt population.

Dolly Varden may also contribute to the predation in Afognak Lake, but Roelofs (1964) examined this possibility and found no merit. Roelofs observed the bulk of the Dolly Varden to have migrated out of the river prior to the smolt outmigration. Armstrong (1965) examined 1,372 emigrating Dolly Varden from Eva Lake on Baranof Island and found 79% of the stomachs empty. Roos (1959) examined 2,338 Dolly Varden leaving from Chignik Lake and found 63% of their stomachs empty. Of the foods items found in the stomachs of Dolly Varden emigrating from Alaska lakes, insects were by far the most common and only a small percentage of juvenile salmon were present even though large numbers of sockeye salmon were emigrating at the same time (Armstrong 1965; DeLacy 1941; Roos 1959). It is purported that the greatest amount of feeding by Dolly Varden occurs in the sea during summer (Armstrong 1965; DeLacy 1941; Roos 1959). When Dolly Varden migrate into streams and lakes in July, and inhabit streams through October, foods most often consumed are salmon eggs and insects (Armstrong 1965; DeLacy 1941; Reed 1967; Roelofs 1964). Most salmon eggs consumed by Dolly Varden are drifting eggs that have washed out of redds at the time of deposition or have been dislodged during subsequent salmon spawning and are unviable (Armstrong 1965; Reed 1967).

Dolly Varden are opportunistic feeders and shift their feeding habits to the prey items that are most abundant (Denton et al. 2009). Dolly Varden fed heavily on sockeye salmon fry when available, shifted their diet almost exclusively to eggs after salmon spawning commenced, and then shifted to blowfly larvae toward the end of the season (Denton et al. 2009). Roos (1959) concluded that it appears unlikely that that the Dolly Varden are a serious predator upon the salmon populations in the Chignik system and that the numbers are low enough not to have any real impact on the population as a whole. In winter Dolly Varden feed very little and most stomachs examined from Dolly Varden were empty (Armstrong 1965). Further research on sockeye predation by Dolly Varden during the period when the sockeye salmon fry emerge from spawning tributaries would be beneficial to estimate population effects on sockeye salmon juveniles rearing in Afognak Lake.

ADULT SALMON ASSESSMENT

The adult sockeye salmon escapement into Afognak Lake has consistently met the lower escapement goal in the last 12 years (Appendix A14; Figure 12). Additionally, the sockeye salmon escapement has met or been near the upper bound of the BEG in the last 7 years.

Return per spawner (R/S) for sockeye salmon in Afognak Lake tends to inversely mirror escapement data, increasing when escapements are low and decreasing when escapements are large (Figure 14). Afognak Lake was fertilized from 1990–2000 and had some of its greatest escapements recorded over those years, followed by its lowest escapements from 2001 to 2007 (Appendix A14). Concurrent with fertilization, backstocking occurred in 1992, 1994, and 1996 to 1998, when approximately 1.53 million fingerling and 523,500 presmolt were released into Afognak Lake (Honnold and Schrof 2004). The increased population size of rearing juveniles from the combination of high escapements and backstocking elevated competition for food resources and limited overall production, as evidenced by low R/S, despite fertilization.

Specifically, the average R/S for all years in Afognak Lake is 1.5, ranging from 0.1 to 3.9 (Appendix A14). During the last 5 years of fertilization (1996–2000), average R/S was well below replacement levels at 0.3 but typically achieved replacement two years after fertilization ceased. The relationship between escapements and R/S (Figure 14; Appendix A14) shows that Afognak Lake sockeye salmon production is density-dependent and caution should be taken to avoid overescapement, nutrient addition projects, and the introduction of supplemental fish via backstocking simulataneously in the future.

The 2016 commercial harvest from the Afognak Bay portion of the Southeast Afognak Section (252-34) of 7,563 sockeye salmon was below the average of 12,040 (1978–2015), but slightly above the most recent 5-year (7,515) and pre-fertilization (4,979) averages (1978–1988; Table 5). These pre-fertilization averages exclude 1989 when the commercial fishery was closed due to the Exxon Valdez oil spill.

Monitoring of adult coho salmon escapement into Afognak Lake was secondary to monitoring sockeye salmon escapement. Weir removal was primarily dependent on budgetary constraints and not conducting an assessment on the coho salmon escapement. Coho salmon escapement counts through the weir were incomplete and dependent on run timing and when the weir was removed.

Coho salmon escapement has averaged approximately 7,177 fish since 1990 and currently has no escapement goal established. An SEG of 3,500–8,000 (passage through the weir by 15 September) was reported by Nelson and Lloyd (2001) but the SEG was eliminated due to early weir removal (Nelson et al. 2005). In 2016, the coho salmon escapement of 4 was well below average due to the weir being pulled out on 27 July, but the most recent 5-year average is 4,979 coho salmon (Appendix A5; Figure 15).

LIMNOLOGICAL ASSESSMENT

Temperatures in the lake were above a 27-year average (1989–2015) during seasonal limnological sampling for 2016 (Appendix A6). Seasonal DO values were slightly above the most recent 10-year average (Appendix A7), which suggests that increased primary production and wind-mixing kept the lake oxygenated. Euphotic zone depth (EZD) values indicated that, on average, the first 7.4 meters of the water column at the sampling stations were photosynthetically active, indicating that the majority of Afognak Lake was capable of primary production throughout the sampling season (average lake depth of 9.2 m).

Seasonal measurements of mean nutrient concentrations, with the exception of TKN, generally showed little variation over the sampling season. From a historical perspective, pH was slightly above average, which can be expected with an increase in the lake temperature and phytoplankton production (Wetzel 1983; Appendix A9). Phosphorus components remained below the historical average (Appendix A10). TKN, which was five times greater than the historical average, was driven by the high July sample (2,058.0 μg/L; Table 10). The TKN sample for August was unable to be analyzed, which may have provided greater insight into possible trends, and the September TKN sample was below the lower detection limit. Even with short water-residence times and increased phytoplankton production, it is unlikely that TKN could have been depleted enough in a one to two month period to shift the lake from a eutrophic (1–2 mg/L) to an oligotrophic (0.05 mg/L) state (Vollenweider 1979). Further, without coincident increases in chl *a*, ammonia, or TP levels, we hypothesize that the high TKN measurements were likely due to experimental error during water analysis contracted to University of Georgia Feed and Environmental Water Laboratory (Table 10).

Mean phytoplankton biovolume in Afognak Lake has increased each year since 2011 (Appendix A16). Afognak Lake phytoplankton are apparently benefiting from mild winters, increased temperatures, and extended growing seasons. Recent mild winters and ice-free lake conditions probably facilitated frequent mixing of the water column and benthic substrate during prevalent wind events, establishing a temporally nutrient-rich environment that the phytoplankton community, especially diatoms and chlorophytes, exploit each spring (Thomsen and Ruhl 2015; Table 14; Figure 16).

In temperate zones, phytoplankton increase greatly in the spring, decline in the summer, and increase again in the fall (Sommer et al. 1986). Zooplankton are generally at their maximum abundance in midsummer; their grazing on the phytoplankton causes a decrease in the phytoplankton stock in the summer (top-down control). Diatoms are the preferred phytoplankton prey for zooplankton in northern lakes and tend to dominate in oligotrophic systems with sufficient silicon concentration (Officer and Ryther 1980). Several of the larger oligotrophic lakes in Kodiak are predominately composed of diatom phytoplankton communities (Finkle 2013; Thomsen 2011). Low nutrient levels favor some diatom species because they can store phosphorus, unlike other phytoplankton taxa (Wehr and Sheath 2003). Diatoms showed the greatest species diversity and population densities in the phytoplankton of Afognak Lake since 2012; however the percent contribution of diatom biovolume to the total community has decreased, likely due to interspecific competition for scarce nutrients (ie; chrysophytes and chlorophytes; Appendix A16).

Dominant species of phytoplankton in Afognak Lake have varied over the 6 years of sample collection, but the community typically has been composed of species that can tolerate oligotrophic nutrient levels and frequent physical disturbances (Wehr and Sheath 2003). For example, the diatoms *Asterionella* and *Cyclotella*, which were major components of the 2016 diatom community, are responsive to frequent changes in environmental conditions, have very short replication rates, and function well at low nutrient levels. *Asterionella* has the ability to continue growth under nutrient-limiting conditions by changing cell metabolism and cell composition (Krivtsov et al 2000).

The seasonal mean zooplankton density and biomass estimates were low in Afognak Lake over the sampling season but slightly above the most recent 5- and 10-year averages. Recent biomasses (177.2 mg/m^2) continue to remain near the starvation level of 100 mg/m^2 for rearing salmonids (2011–2015; Mazumder and Edmundson 2002). Data from the cladoceran *Bosmina* suggested that juvenile sockeye salmon may overgraze this key taxa; *Bosmina* were small (mean length of 0.30 mm) and well below the juvenile sockeye salmon minimum selective feeding threshold of 0.40 mm (Kyle 1992). The low biomass and size of zooplankton in Afognak Lake may also be the result of competition for resources with aquatic insects, poorly ingestible phytoplankton, fish predation, or temperature (Thorp and Covich 2001).

CONCLUSIONS

Afognak Lake is unlike other Kodiak Island sockeye salmon systems in that it is small (in volume) and shallow, and has a high flushing rate (146 days), hence low retention of nutrients. High flushing rates affect in-lake temperature regimes and nutrient supply from the catchment (Bailey-Watts et al. 1990) and indirectly limit algal growth and composition, influencing phytoplankton timing and succession rates, the development and decline of zooplankton that prey upon them, and, consequently, smolt development. Nutrient loading in Afognak Lake is controlled mainly by precipitation events (runoff), spring/fall turnover events, and wind-induced disturbance and mixing of the benthic substrate. Koenings and Burkett (1987) estimated that salmon-derived nutrients (SDN) from decomposing salmon carcasses provide up to 60% of the total P and N budget in typical oligotrophic lakes. However, a sediment core study (Holtham et al. 2004) of 3 shallow oligotrophic Alaskan sockeye systems, including Afognak Lake, investigated the influence of flushing rates on nutrient loading and suggested that SDN may have limited importance in oligotrophic lakes with frequent water cycling because they are being rapidly removed from the ecosystem.

Afognak Lake has been subject to several recent manipulations to increase salmon production. Nutrient enrichment was implemented for 11 years (1990–2000), and backstocking of sockeye fingerling and pre-smolt occurred simultaneously under the assumption that the system could sustain increased rearing sockeye during nutrient additions, but this method apparently increased competition for food resources and decreased R/S in subsequent years (Figure 14; Appendix A14). The relationship between escapements and R/S shows that Afognak Lake sockeye salmon production is density-dependent and several successive years of overescapement, fertilization, or backstocking combined can impose detrimental effects that can take years to recover from, as was experienced from 2001 through 2007, culminating in commercial, subsistence, and sport fishing closures or restrictions.

Alaska salmon production fluctuates naturally as a result of patterns and synchronous climate anomalies in sea surface temperatures in the North Pacific, or Pacific Decadal Oscillations (PDOs; Beamish and Bouillon 1993; Beamish et al. 1999; Mantua 2009). The more extreme regime shifts of the PDO have been classified as either “warm” (positive) or “cool” (negative) phases, with total salmon production in Alaska high when the PDO is in a warm phase and vice versa for cool phases (Hare and Francis 1994). Supporting this statement, sockeye salmon experienced a decrease in production in the late 1940s and an increase in production in the late 1970s with shifts in climate (Hare and Francis 1994). The warm phase is generally characterized by increased ocean temperatures and productivity in the Pacific Basin, thus greater prey abundance and survival for feeding salmon (Mantua et al. 1997; Mantua 2009).

Based solely on adult returns to Afognak Lake, the combination of lake enrichment and backstocking appeared to increase sockeye salmon production, but highly productive ocean conditions coincided with fertilization (1977 through mid-1990’s; Mantua and Hare 2002; PDO), confounding the overall success of the fertilization program in Afognak Lake. Beamish et al. (1997) found that the rate of increased salmon production appeared unrelated to the number of juveniles entering the marine environment, suggesting ocean conditions have a stronger influence on the abundance trends of Pacific salmon. Accordingly, the post-fertilization decline (2001–2009) of salmon returns to Afognak Lake may be linked to the negative regime shift that is thought to have occurred in 1998 through 2002 (Jo et al. 2013; Overland et al. 2008; Peterson and Schwing 2003) and intensified by the lack of continued nutrient additions to the system.

Average annual temperatures in Alaska are projected to rise 3.5–7°C by the middle of this century (Karl et al. 2009). Warmer lake temperatures will shift the spring thaw earlier and lengthen the growing season, but warmer temperatures will also increase metabolic rates, forcing juveniles to alter feeding behavior and seek refuge in cooler, deeper water. Additionally, stratification of lakes will be earlier and stronger, will last longer, and will alter nutrient availability. Although increased temperatures will likely increase phytoplankton and zooplankton production, Carter (2010) also points out that earlier stratification in some systems affected food availability timing and reduced zooplankton clutch size and reproductive activity with warmer temperatures, decreasing production. Productivity and emergence of insects, a key prey for sockeye salmon juveniles in Afognak Lake throughout the season, will likely be altered. If changes in insect emergence do not coincide with juvenile needs, significant mortality may occur. Over time, emergence, smolt outmigration, adult returns, and spawning would probably become earlier.

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TABLES AND FIGURES

Table 1.–Estimated abundance of sockeye salmon smolt outmigrating from Afognak Lake, 2016.

Stratum	Starting	Ending	Catch	Released	Recaptured	Carlson trap	Estimate	Variance	95% Confidence interval	
(h)	date	date	(u_h)	(M_h)	(m_h)	efficiency (%)	(U_h)	(U_h)	Lower	Upper
1	2-May	19-May	2,456	522	52	10.13%	24,414	9,985,805	18,219	30,607
2	20-May	24-May	3,554	546	47	9.14%	38,883	30,950,698	27,980	49,788
3	25-May	31-May	9,581	539	75	19.53%	49,052	1,233,192	34,901	63,203
4	1-Jun	6-Jun	17,277	548	150	29.26%	59,053	18,983,392	50,513	67,593
5	7-Jun	14-Jun	4,126	547	45	8.93%	48,824	47,615,054	35,299	62,349
6	15-Jun	23-Jun	1,531	504	108	22.02%	6,952	384,202	5,737	8,167
Total			38,525	3,206	477	16.50%	227,178	109,152,343	172,650	281,706
							SE = 12,651			

Note: The parameters h, M_h, m_h, U_h, and u_h are used to calculate the outmigration estimate and are defined on page 5 and 6.

Table 2.–Sockeye salmon smolt catch, number of AWL samples collected, mark–recapture releases and recoveries, and trap efficiency estimates from Afognak River by stratum, 2016.

Date	Sockeye smolt		Trap efficiency test		Carlson
Stratum 1	Daily	Samples	Releases[a]	Recoveries	efficiency
2-May	38	5			10.1%
3-May	28	30			10.1%
4-May	25	15			10.1%
5-May	55	15			10.1%
6-May	47				10.1%
7-May	18				10.1%
8-May	24				10.1%
9-May	77				10.1%
10-May	72				10.1%
11-May	98				10.1%
12-May	56				10.1%
13-May	78				10.1%
14-May	202				10.1%
15-May	188	20	522	34	10.1%
16-May	219	20		10	10.1%
17-May	450	40		8	10.1%
18-May	442			0	10.1%
19-May	339	30		0	10.1%
Total Stratum 1	2,456	175	522	52	10.1%
Stratum 2					9.1%
20-May	334	30	546	28	9.1%
21-May	830	60		18	9.1%
22-May	631	40		1	9.1%
23-May	494				9.1%
24-May	1,265	40			9.1%
Total Stratum 2	3,554	170	546	47	9.1%
Stratum 3					19.5%
25-May	734	55	539	53	19.5%
26-May	609	40		22	19.5%
27-May[b]	1,167	30		0	19.5%
28-May[b]	1,369	25		0	19.5%
29-May[b]	1,606	17			19.5%
30-May[b]	1,885				19.5%
31-May[b]	2,211				19.5%
Total Stratum 3	9,581	167	539	75	19.5%

-continued-

Table 2.–Page 2 of 2.

Date	Sockeye smolt		Trap efficiency test		Carlson
Stratum 4	Daily	Samples	Releases[a]	Recoveries	efficiency
1-Jun	1,948	100	548	97	29.3%
2-Jun	3,478	95		47	29.3%
3-Jun	3,464	100		6	29.3%
4-Jun	3,533	100			29.3%
5-Jun	3,257	65			29.3%
6-Jun	1,597	35			29.3%
Total Stratum 4	17,277	495	548	150	29.3%
Stratum 5					
7-Jun	781	30	547	23	8.9%
8-Jun	678			18	8.9%
9-Jun	624			2	8.9%
10-Jun	445	40		0	8.9%
11-Jun	540	20		0	8.9%
12-Jun	551	25			8.9%
13-Jun	320	15			8.9%
14-Jun	187	10			8.9%
Total Stratum 5	4,126	140	547	43	8.9%
Stratum 6					22.0%
15-Jun	344		504	63	22.0%
16-Jun	317	15		40	22.0%
17-Jun	231	10		3	22.0%
18-Jun	93	5		2	22.0%
19-Jun	204	10		0	22.0%
20-Jun	146	10		0	22.0%
21-Jun	80	5			22.0%
22-Jun	78	5			22.0%
23-Jun	38	5			22.0%
Total Stratum 6	1,531	65	504	108	22.0%
Total Strata 1–6	38,525	1,212	3,206	475	16.5%

[a] The number of marked releases for each strata were adjusted using delayed mortality tests.

[b] Smolt catch estimates were generated from 27 May–31 May using regression analysis.

Table 3.–Length, weight, and condition of sockeye salmon smolt, by statistical week and age, from the Afognak River, 2016.

Stat	Date		Sample	Length (mm)		Weight (g)		Condition (*K*)	
week	Starting	Ending	size	Mean	SE	Mean	SE	Mean	SE
				Age-1					
18	26-Apr	2-May	4	66.7	2.17	2.2	0.20	0.75	0.036
19	3-May	9-May	32	70.2	0.74	2.7	0.07	0.78	0.019
20	10-May	16-May	27	71.3	0.60	3.1	0.10	0.72	0.017
21	17-May	23-May	165	74.9	0.23	3.4	0.03	0.81	0.005
22	24-May	30-May	198	77.2	0.25	3.8	0.03	0.82	0.005
23	31-May	6-Jun	491	84.3	0.13	5.1	0.02	0.86	0.003
24	7-Jun	13-Jun	129	86.8	0.23	6.0	0.04	0.91	0.005
25	14-Jun	20-Jun	60	87.4	0.40	6.0	0.08	0.90	0.008
26	21-Jun	27-Jun	13	87.9	0.75	6.2	0.18	0.91	0.011
Totals[a]			1119	81.4	0.17	4.7	0.03	0.85	0.002
				Age-2					
18	26-Apr	2-May	1	78.0	0.00	2.9	0.00	0.61	0.000
19	3-May	9-May	28	80.1	0.87	3.8	0.13	0.73	0.023
20	10-May	16-May	13	80.4	0.87	3.9	0.14	0.75	0.016
21	17-May	23-May	35	79.7	0.62	4.0	0.09	0.78	0.014
22	24-May	30-May	9	81.2	1.27	4.2	0.21	0.78	0.015
23	31-May	6-Jun	4	84.3	0.25	5.3	0.14	0.88	0.016
Totals[a]			90	80.3	0.41	4.0	0.07	0.76	0.010

[a] Mean values are weighted.

Table 4.–Estimated outmigration abundance of Afognak Lake sockeye salmon smolt by time period (stratum) and freshwater age class, 2016.

	Date			Age			
Stratum	Starting	Ending		1	2	3	Total
1	2-May	19-May	Number	15,848	8,565	0	24,413
			Percent	64.9%	35.1%	0.0%	
2	20-May	24-May	Number	33,402	5,482	0	38,884
			Percent	85.9%	14.1%	0.0%	
3	25-May	31-May	Number	48,867	185	0	49,052
			Percent	99.6%	0.4%	0.0%	
4	1-Jun	6-Jun	Number	58,735	318	0	59,053
			Percent	99.5%	0.5%	0.0%	
5	7-Jun	14-Jun	Number	48,824	0	0	48,824
			Percent	100.0%	0.0%	0.0%	
6	15-Jun	23-Jun	Number	6,952	0	0	6,952
			Percent	100.0%	0.0%	0.0%	
Total			Number	212,628	14,550	0	227,178
			Percent	93.6%	6.4%	0.0%	

Table 5.–Afognak Lake sockeye salmon escapement, harvest, and total run estimates, 2011–2016.

		Harvest [a]			
Year	Escapement	Commercial [b]	Subsistence [c]	Total	Total Run
2011	49,193	13,858	1,978	15,836	65,029
2012	41,553	3,398	1,731	5,129	46,682
2013	42,153	6,311	2,012	8,323	50,476
2014	36,345	9,753	3,001	12,754	49,099
2015	38,151	4,254	1,892	6,146	44,297
2016	33,167	7,563	3,275	10,838	44,005
Average (2011–2015)	41,479	7,515	2,123	9,638	51,117

[a] Sport harvest data does not have enough respondents to provide reliable estimates and was determined to be negligible.

[b] Statistical fishing section 252-34 (Southeast Afognak Section).

[c] Data as of 02/24/2017 from ADF&G subsistence catch database.

Table 6.–Afognak Lake adult sockeye salmon escapement by statistical week and age class, 2016.

Date		Sample		Age							
Starting	Ending	Size		0.3	1.1	1.2	1.3	1.4	2.2	2.3	Total Fish
10-May	16-May	49	Percent	0.00	0.00	2.12	67.43	0.02	0.09	30.34	
			Numbers	0	0	16	445	1	3	191	656
17-May	23-May	166	Percent	0.00	0.00	4.47	68.85	0.43	2.56	23.69	
			Numbers	0	0	91	1,381	7	51	505	2,035
24-May	30-May	332	Percent	0.00	0.00	5.82	62.60	0.10	3.93	27.55	
			Numbers	0	0	377	3,899	2	284	1,739	6,301
31-May	6-Jun	328	Percent	0.00	0.00	7.46	63.58	0.00	9.21	19.75	
			Numbers	0	0	462	4,478	0	598	1,356	6,894
7-Jun	13-Jun	228	Percent	0.00	0.85	14.54	55.48	0.00	13.95	15.17	
			Numbers	0	22	771	3,539	0	811	1,063	6,206
14-Jun	20-Jun	180	Percent	0.00	2.13	20.03	53.17	0.00	15.09	9.58	
			Numbers	0	58	562	1,508	0	424	278	2,830
21-Jun	27-Jun	112	Percent	0.00	0.76	18.37	54.82	0.00	12.73	13.31	
			Numbers	0	10	305	931	0	210	233	1,689
28-Jun	4-Jul	118	Percent	0.00	7.60	22.69	46.15	0.00	15.85	7.71	
			Numbers	0	105	439	915	0	299	159	1,917
5-Jul	11-Jul	57	Percent	0.26	14.26	18.51	41.09	0.26	18.62	7.00	
			Numbers	3	230	288	630	3	275	108	1,537
12-Jul	18-Jul	116	Percent	0.64	6.44	17.11	43.23	0.64	22.12	9.82	
			Numbers	13	124	301	767	13	416	155	1,789
19-Jul	25-Jul	73	Percent	1.73	3.33	18.10	46.07	0.08	16.78	13.90	
			Numbers	19	31	148	383	1	144	105	831
26-Jul	1-Aug	13	Percent	7.69	7.69	15.38	46.15	0.00	23.08	0.00	
			Numbers	37	37	74	223	0	111	0	482
		1,772	Percent	0.2%	1.9%	11.6%	57.6%	0.1%	10.9%	17.8%	100.0%
			Numbers	72	617	3,834	19,099	27	3,626	5,892	33,167

Table 7.–Mean length of Afognak Lake adult sockeye salmon escapement by sex and age class, 2016.

	Age							
	0.3	1.1	1.2	1.3	1.4	2.2	2.3	Total
Females								
Mean Length (mm)	521.00	0.00	471.32	519.51	0.00	475.23	510.20	508.65
Standard Error	0.00	0.00	2.66	1.01	0.00	2.54	1.78	1.58
Range	521-521	0.00	422-562	451-763	0.00	434-580	423-598	422-763
Sample Size	1	0	104	637	0	101	213	1,056
Males								
Mean Length (mm)	569.00	351.33	468.81	535.04	520.00	479.42	524.75	509.51
Standard Error	0.00	3.56	3.58	1.38	6.00	3.86	2.41	1.92
Range	569-569	311-392	397-576	441-605	514-526	400-582	462-585	311-605
Sample Size	1	30	104	386	2	86	107	716
All								
Mean Length (mm)	545.00	351.33	470.06	525.37	520.00	477.16	515.07	509.00
Standard Error	24.00	3.56	2.23	0.85	6.00	2.24	1.48	0.96
Range	521-569	311-392	397-576	441-763	514-526	400-582	423-598	311-763
Sample Size	2	30	208	1,023	2	187	320	1,772

Table 8.–Data logger temperatures (°C) at 1 m water depth, Station 2, Afognak Lake, 2010–2016.

	Temperature (°C)																				
	Average							Maximum							Minimum						
Month	2010	2011	2012	2013	2014	2015	2016	2010	2011	2012	2013	2014	2015	2016	2010	2011	2012	2013	2014	2015	2016
May	7.3	7.3	7.3	8.1	13.1	9.2	11.9	9.2	9.9	9.5	10.6	14.2	12.9	14.9	5.9	6.6	5.7	7.1	12.0	8.0	9.8
June	11.3	11.0	12.3	13.3	13.6	15.3	15.0	13.5	13.7	16.7	17.4	15.6	18.7	17.3	8.8	8.5	8.1	9.0	12.8	12.4	13.0
July	14.0	15.1	14.4	17.5	16.8	16.6	17.8	15.7	17.1	17.3	21.8	18.0	18.8	19.3	12.4	13.1	12.4	14.3	15.3	15.5	15.8
August	14.8	15.8	14.8	16.1	16.6	17.7	17.6	16.1	17.6	16.3	18.8	17.9	20.0	19.0	14.0	14.5	14.3	15.2	15.9	14.5	16.7
September	14.3	12.4	12.5	14.5	14.6	14.0	17.6	15.7	14.8	15.0	15.9	15.8	14.8	21.8	11.8	10.7	9.8	13.3	12.1	13.2	11.3
October	9.9	10.4	9.4	–	9.0	–	–	11.8	10.7	9.9	–	11.9	–	–	8.2	10.0	9.2	–	7.0	–	–
Spring (May–June)	9.3	9.1	9.8	10.7	13.4	12.3	13.5	13.5	13.7	16.7	17.4	15.6	15.8	16.1	5.9	6.6	5.7	7.1	12.0	10.2	11.4
Summer (July–Aug)	14.4	15.4	14.6	16.8	16.7	17.2	17.7	16.1	17.6	17.3	21.8	18.0	19.4	19.2	12.4	13.1	12.4	14.3	15.3	15.0	16.3
Fall (Sept–Oct)	12.1	11.4	11.0	14.4	11.8	14.0	17.6	15.7	14.8	15.0	15.9	15.8	14.8	21.8	8.2	10.0	9.2	13.3	7.0	13.2	11.3
Season (May–Oct)	12.3	12.8	12.6	14.4	14.3	14.6	16.0	16.1	17.6	17.3	21.8	18.4	17.0	18.5	5.9	6.6	5.7	7.1	6.9	12.7	13.3

Table 9.–General water chemistry and algal pigment concentrations at 1 m water depth, Station 1, Afognak Lake, 2016.

Date	pH	Alkalinity (mg/L)	Chlorophyll *a* (µg/L)	Phaeophytin *a* (µg/L)
16-May	7.69	8.5	1.60	1.54
15-Jun	7.66	9.5	1.92	0.77
12-Jul	7.79	10.0	2.24	0.45
15-Aug	7.82	10.3	1.60	1.31
13-Sep	7.89	12.5	2.24	0.67
Average	7.77	10.2	1.92	0.95
SD	0.09	1.5	0.32	0.46

Table 10.–Seasonal phosphorus and nitrogen concentrations at 1 m water depth, Station 1, Afognak Lake, 2016.

Date	Total filterable-P (µg/L)	Filterable reactive-P (µg/L)	Total-P (µg/L)	Reactive Silicon (µg/L)	Ammonia (µg/L)	Total Kjeldahl Nitrogen (µg/L)	Nitrate + Nitrite (µg/L)	Total Nitrogen (µg/L)	TN:TP ratio
16-May	2.1	1.7	5.7	1,757.4	5.2	1,098.0	68.3	1,166.3	453.1
15-Jun	1.4	1.4	4.2	2,129.8	10.6	1,048.0	37.4	1,085.4	572.2
12-Jul	2.0	1.4	3.4	2,551.7	2.1	2,058.0	11.3	2,069.3	1,347.6
15-Aug	2.1	1.4	4.8	2,077.9	13.1	ND	10.8	10.8	-
13-Sep	1.5	1.2	4.1	1,709.2	9.3	50.0	19.8	69.8	37.7
Average	1.8	1.4	4.4	2,045.2	8.1	1,063.5	29.5	880.3	602.7
SD	0.3	0.2	0.9	339.3	4.4	820.1	24.2	858.9	546.9

Note: ND = no data.

Table 11.–Seasonal average zooplankton abundances (number/m^2) from Afognak Lake, 2016.

Taxon	Date 16-May	15-Jun	12-Jul	15-Aug	13-Sep	Seasonal average
Cladocerans:						
Bosmina	13,535	148,089	198,779	64,358	48,169	94,586
Ovig. *Bosmina*	796	6,901	1,460	-	2,522	2,336
Daphnia l.	-	1,327	15,791	3,450	2,256	4,565
Ovig. *Daphnia l.*	-	-	664	-	-	133
Holopedium	2,389	12,739	13,934	-	-	5,812
Ovig. *Holopedium*	398	664	796	-	-	372
Immature Cladocera	5,574	35,165	14,199	2,654	2,654	12,049
Total Cladocerans:	22,691	204,884	245,621	70,462	55,600	119,851
Copepods:						
Cyclops	7,166	3,848	1,991	531	2,920	3,291
Diaptomus	2,389	664	664	531	-	849
Epischura	40,605	23,753	61,040	31,980	1,062	31,688
Nauplii	22,293	15,261	19,108	1,858	-	11,704
Total Copepods:	72,453	43,525	82,802	34,899	3,981	47,532
Total Cladocerans + Copepods	95,144	248,408	328,423	105,361	59,581	167,383

Note: Stations 1 and 2 averaged.

Table 12.–Seasonal average zooplankton biomass (mg/m^2) from Afognak Lake, 2016.

Taxon	Date 16-May	15-Jun	12-Jul	15-Aug	13-Sep	Seasonal average	Seasonal weighted average
Cladocerans:							
Bosmina	12.3	120.3	134.4	45.3	33.2	69.1	68.9
Ovig. *Bosmina*	1.7	6.1	1.3	0	2.2	2.2	2.2
Daphnia l.	0	2.3	20.7	3.7	5.9	5.9	5.9
Ovig. *Daphnia l.*	0	0	1.1	0	0.2	0.2	0.2
Holopedium	4.3	28.0	25.1	0	0	11.5	11.5
Ovig. *Holopedium*	1.4	1.5	2.3	0	0	1.0	1.0
Total Cladocerans:	19.7	158.2	184.9	49.0	41.5	89.9	89.6
Copepods:							
Cyclops	14.6	9.6	3.9	1.9	5.8	7.1	7.1
Diaptomus	2.2	4	5.5	2.6	3	2.9	2.5
Epischura	86.9	112.2	110.7	74.1	77.2	77.2	73.5
Total Copepods:	103.7	126.0	120.1	78.6	85.9	87.2	83.1
Total Cladocerans + Copepods	123.4	284.2	305.0	127.6	127.4	177.2	172.7

Note: Stations 1 and 2 averaged.

Table 13.–Seasonal averages of zooplankton lengths (mm) from Afognak Lake, 2016.

	Taxon	Date					Seasonal average length	Weighted average length
		16-May	15-Jun	12-Jul	15-Aug	13-Sep		
Cladocerans:								
	Bosmina	0.33	0.30	0.27	0.28	0.28	0.29	0.29
	Ovig. *Bosmina*	0.47	0.31	0.31	-	0.30	0.35	0.32
	Daphnia l.	-	0.64	0.51	0.52	0.54	0.54	0.56
	Ovig. *Daphnia l.*	-	-	0.63	-	-	0.63	0.63
	Holopedium	0.48	0.50	0.47	-	-	0.49	0.49
	Ovig. *Holopedium*	0.61	0.51	0.57	-	-	0.56	0.56
Copepods:								
	Cyclops	0.76	0.74	0.75	0.99	0.66	0.76	0.78
	Diaptomus	0.58	1.15	1.26	1.05	-	1.01	0.83
	Epischura	0.79	1.02	0.72	0.80	0.74	0.82	0.79

Note: Stations 1 and 2 averaged.

Table 14.–Relative monthly phytoplankton composition and mean biovolumes in Afognak Lake, by phylum, 2016.

	Biovolumes (μm^3/L)					
Phylum - Algal group	16-May	15-Jun	12-Jul	15-Aug	13-Sep	Mean
Bacillariophyta (Diatoms)	85,406,949	228,620,817	212,796,139	142,711,586	194,275,074	172,762,113
	11.3%	21.3%	37.3%	43.5%	71.0%	28.8%
Chlorophyta (Green algae)	227,209,572	447,324,915	7,792,216	5,375,101	6,346,409	138,809,642
	30.1%	41.7%	1.4%	1.6%	2.3%	23.1%
Chrysophyta (Golden-brown algae)	300,437,363	30,086,414	20,735,159	1,791,927	2,216,577	71,053,488
	39.9%	2.8%	3.6%	0.5%	0.8%	11.8%
Cryptophyta (Cryptomonads)	113,411,907	343,761,311	0	24,091,467	40,505,023	104,353,941
	15.0%	32.1%	-	7.3%	14.8%	17.4%
Cyanophyta (Blue-green algae)	936,874	1,152,347	4,149,842	147,333,079	981,566	30,910,741
	0.1%	0.1%	0.7%	44.9%	0.4%	5.2%
Euglenophyta (Euglenids)	7,819,319	9,348,988	0	0	28,425,564	9,118,774
	1.0%	0.9%	-	-	10.4%	1.5%
Pyrrhophyta (Dinoflagellates)	18,433,302	12,274,702	325,137,486	6,625,153	981,566	72,690,442
	2.4%	1.1%	57.0%	2.0%	0.4%	12.1%
Totals	753,655,285	1,072,569,493	570,610,842	327,928,313	273,731,778	599,699,142

Table 15.–Dates the Afognak Weir was installed and removed by year, 1990–2016.

Year	Weir Installed	Weir Removed	Total days in
1990	5/27	9/17	113
1991	5/24	9/8	107
1992	5/24	9/15	114
1993	5/23	9/12	112
1994	5/28	9/18	113
1995	5/29	9/12	106
1996	5/23	9/11	111
1997	5/21	9/13	115
1998	5/20	9/9	112
1999	5/24	9/12	111
2000	5/23	9/11	111
2001	5/26	9/7	104
2002	5/28	8/25	89
2003	5/15	8/23	100
2004	5/15	8/6	83
2005	5/15	8/19	96
2006	5/21	8/4	75
2007	5/21	8/17	88
2008	5/23	8/8	77
2009	5/20	8/6	78
2010	5/19	9/7	111
2011	5/17	8/20	95
2012	5/23	8/25	94
2013	5/23	8/27	96
2014	5/11	8/23	104
2015	5/6	8/17	103
2016	5/4	7/27	84
Average (1990–2015)			101
Average (2006–2015)			92

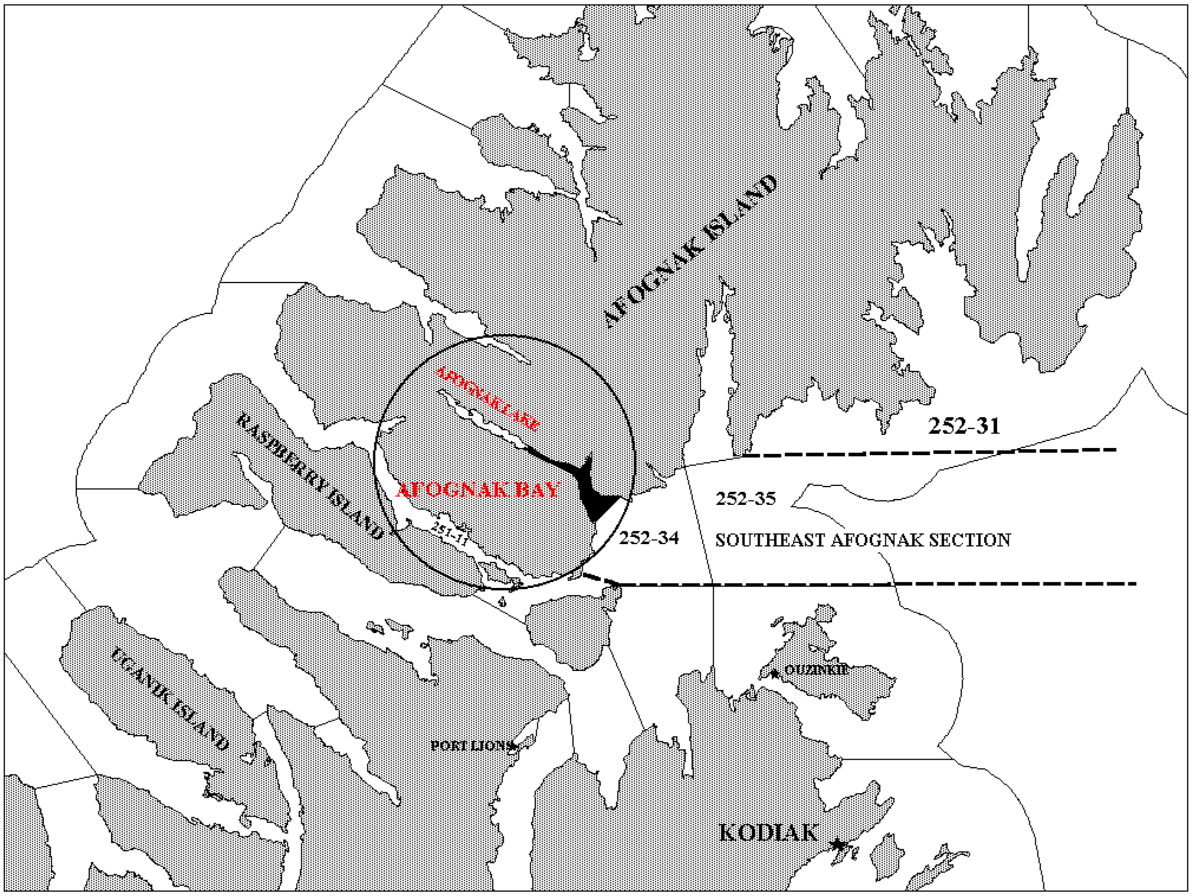

Figure 1.–Map depicting the location of the city of Kodiak, the villages of Port Lions and Ouzinkie, and their proximity to the Afognak Lake drainage on Afognak Island.

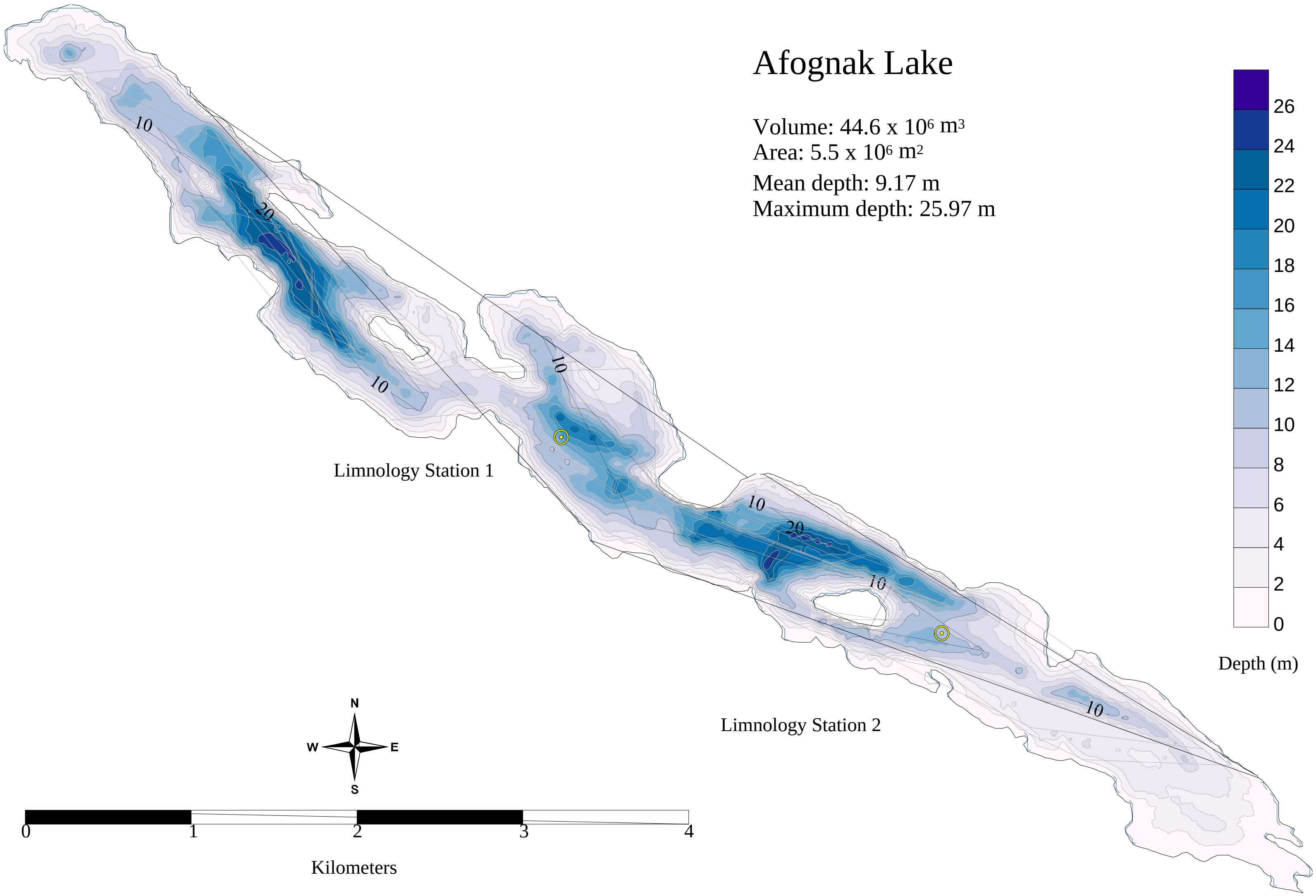

Figure 2.–Bathymetric map showing the limnology and zooplankton sampling stations on Afognak Lake.

Figure 3.–View of the juvenile sockeye salmon inclined plane trapping system, 2016.

Figure 4.–View of the adult salmon enumeration weir and “Scott” trap in Afognak River, 2016.

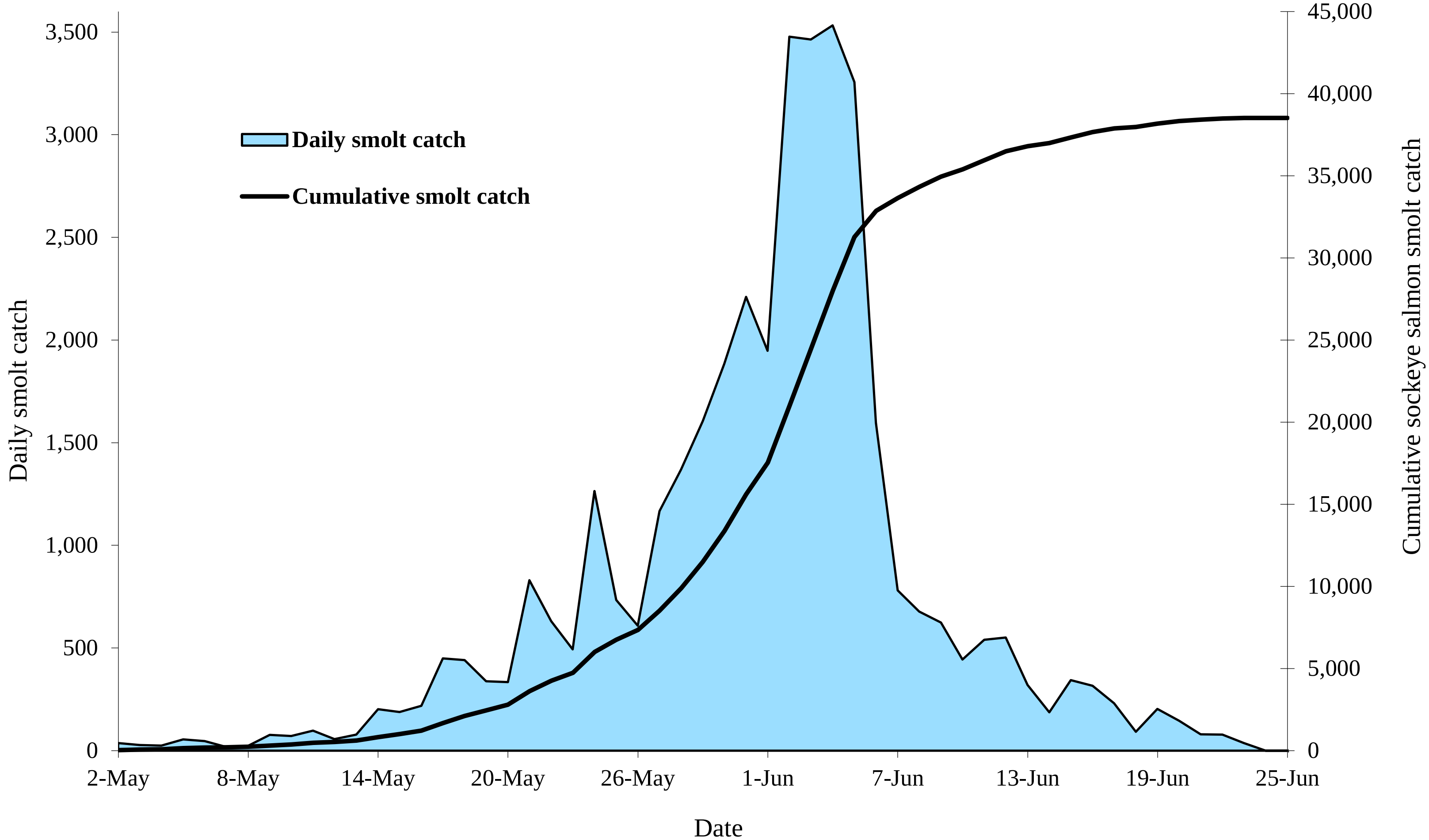

Figure 5.–Daily and cumulative sockeye salmon smolt trap catch from 2 May to 23 June in the Afognak River, 2016.

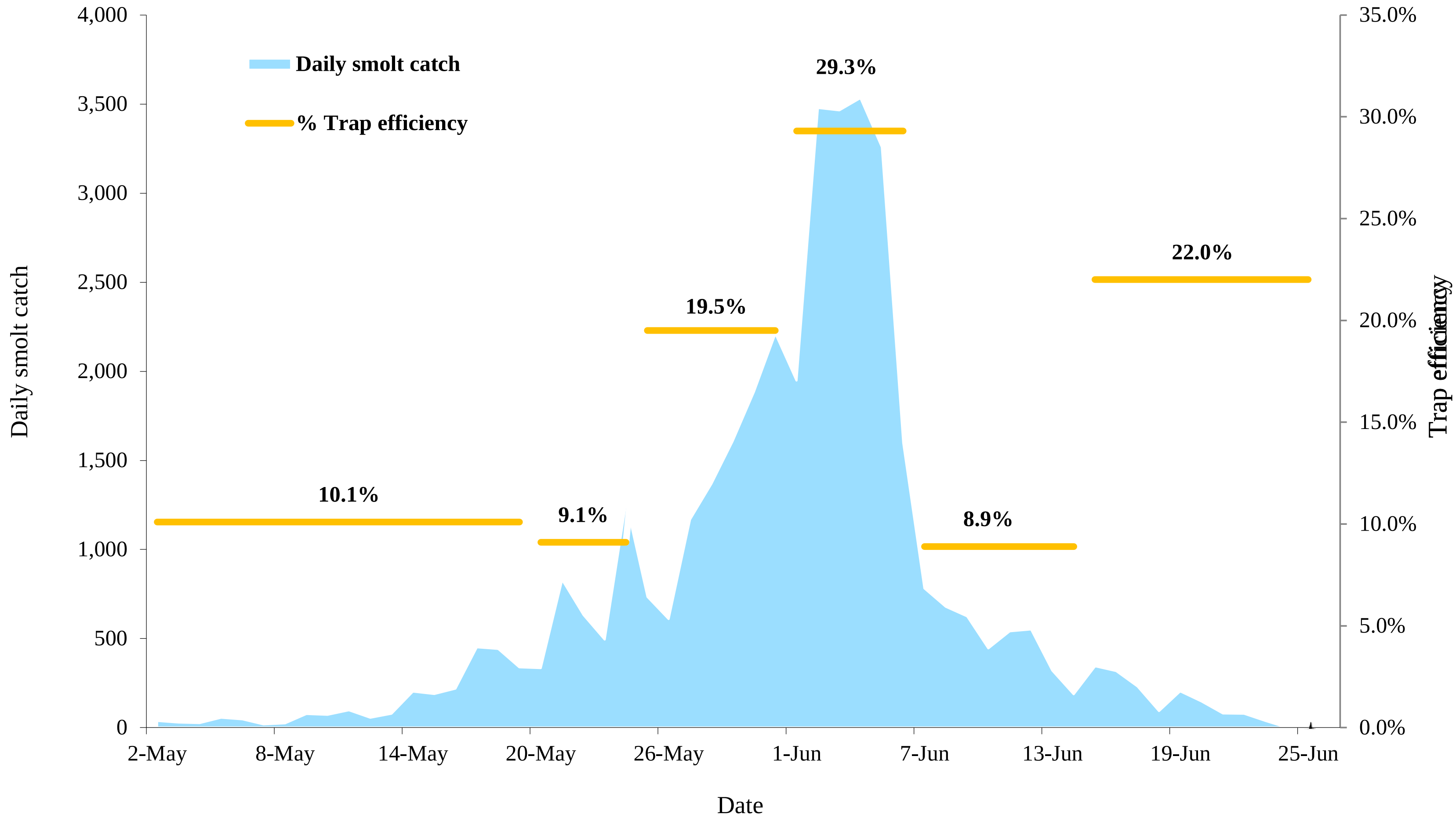

Figure 6.–Daily sockeye salmon smolt trap catch and trap efficiency estimates by strata from 2 May to 23 June in the Afognak River, 2016.

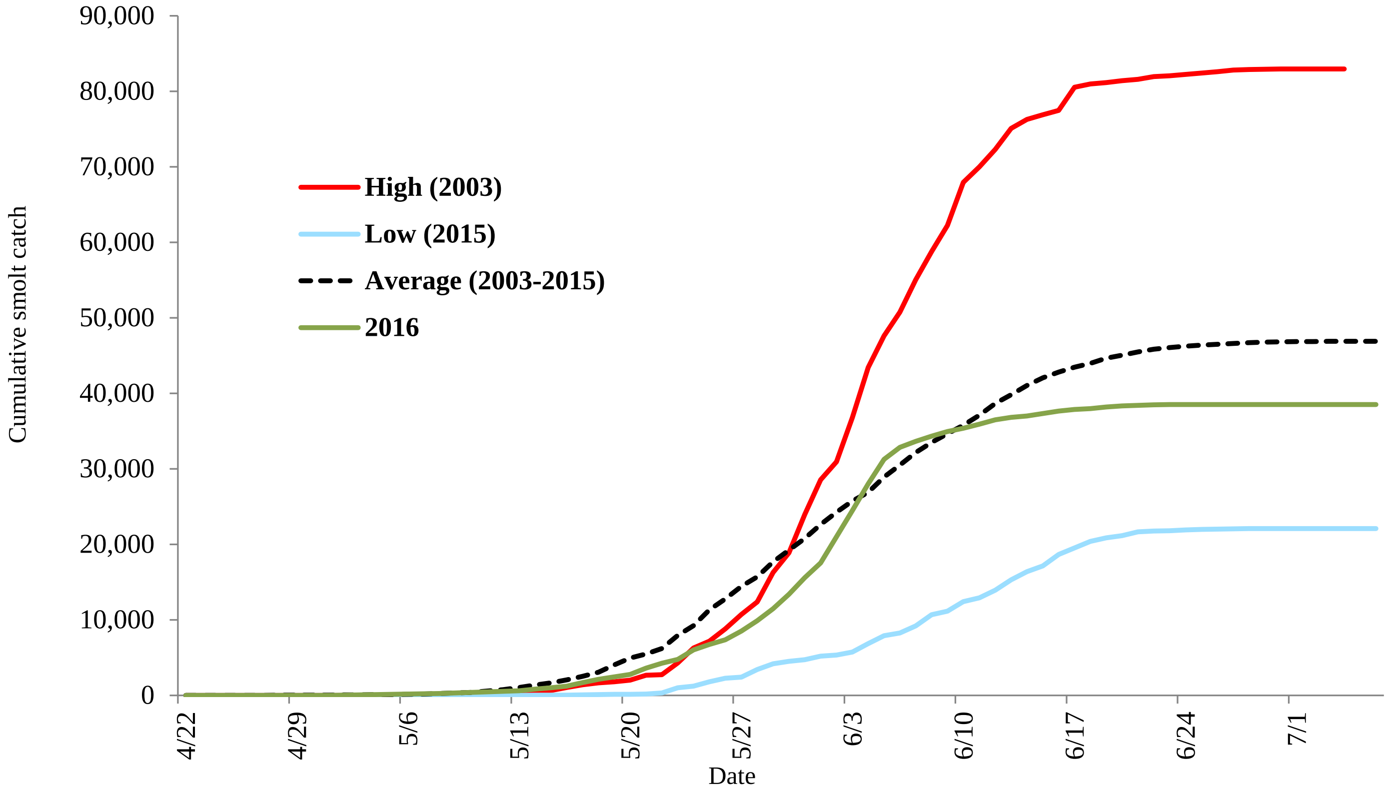

Figure 7.–Comparison of average cumulative sockeye salmon smolt trap catch in the Afognak River, 2003–2016.

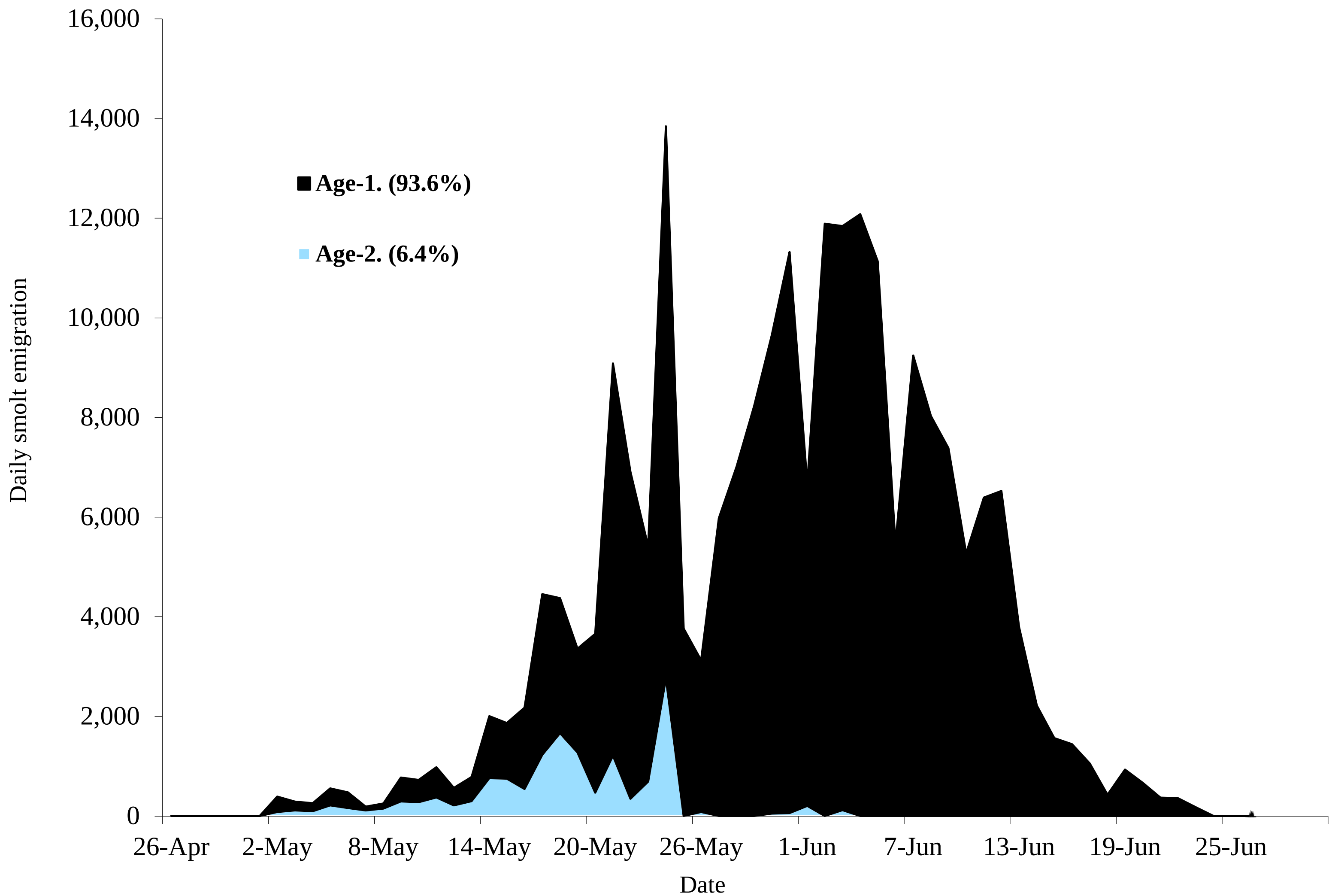

Figure 8.–Afognak Lake sockeye salmon smolt daily outmigration estimates by age class, 2016.

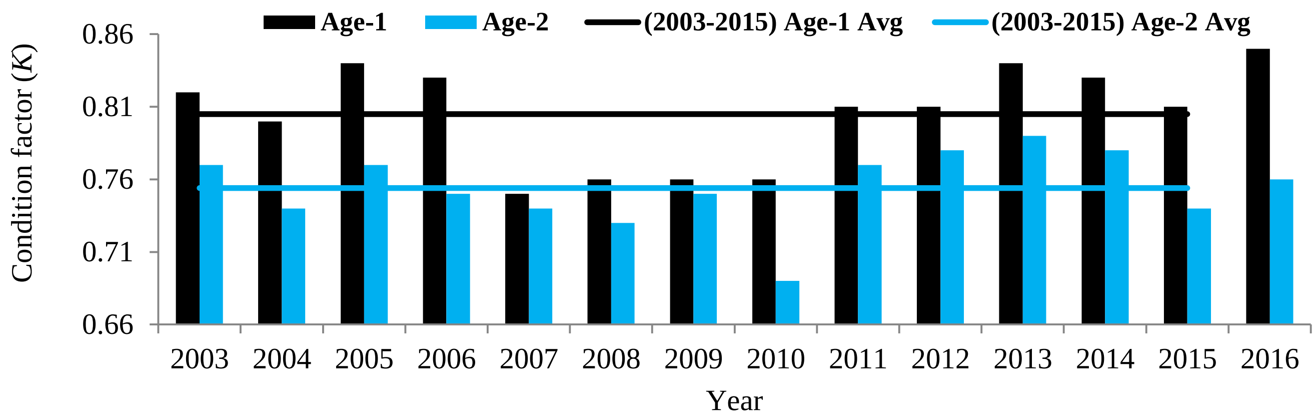

Figure 9.–Relative condition (*K*) of Afognak Lake smolt by year and age, 2003–2016.

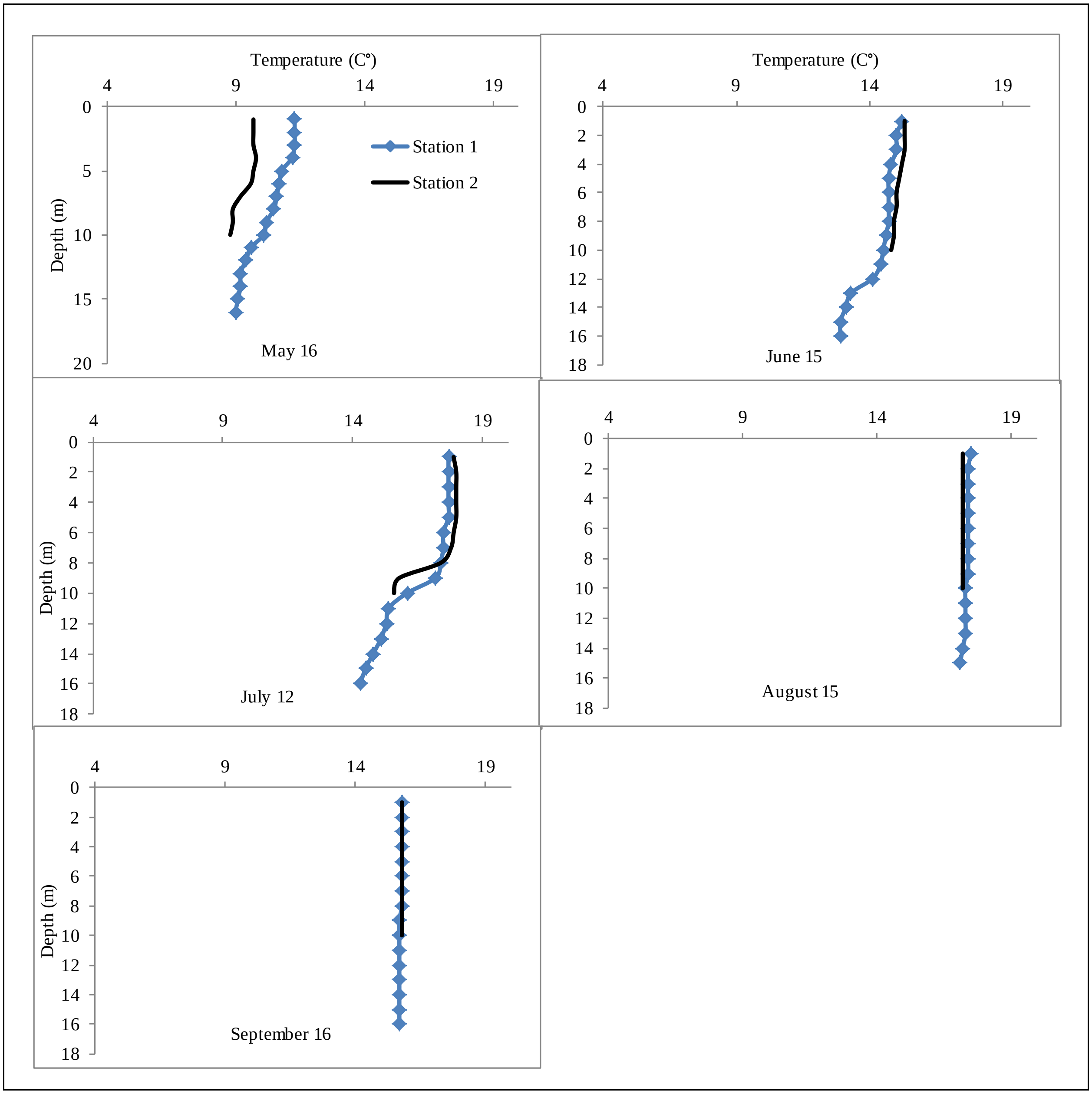

Figure 10.–Temperature profiles by station, by sampling date from Afognak Lake, 2016.

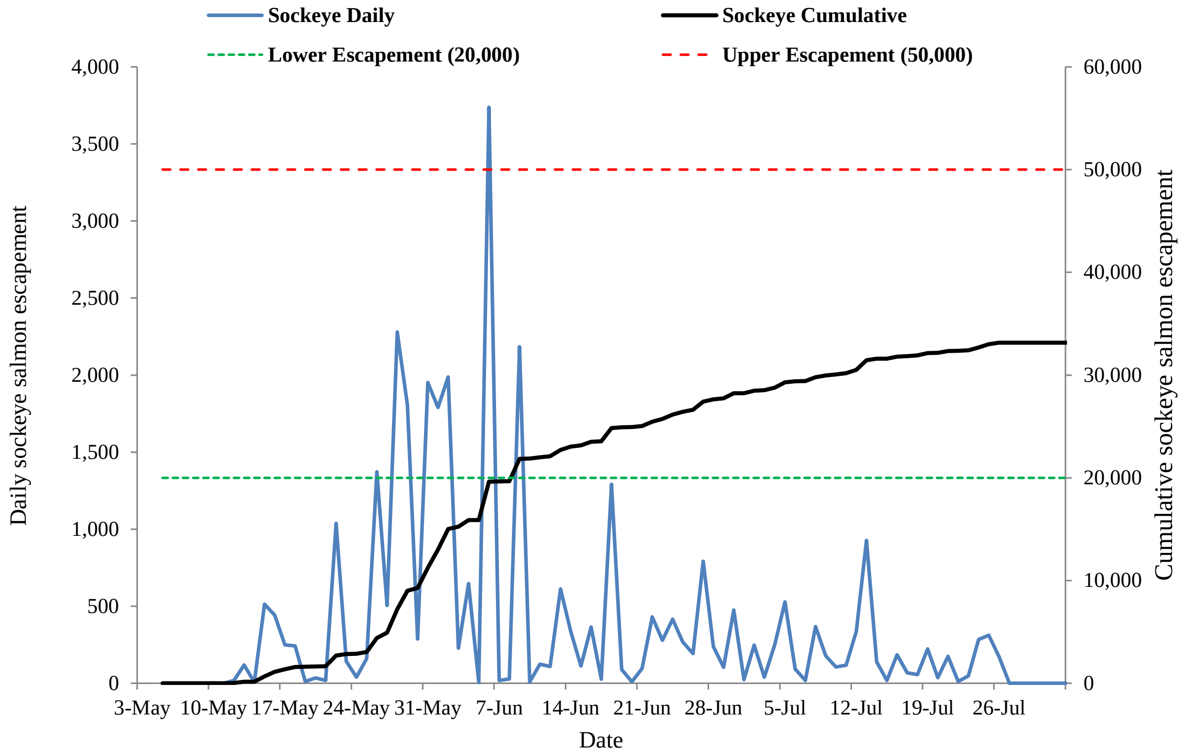

Figure 11.–Afognak Lake adult sockeye salmon daily and cumulative escapement, 2016.

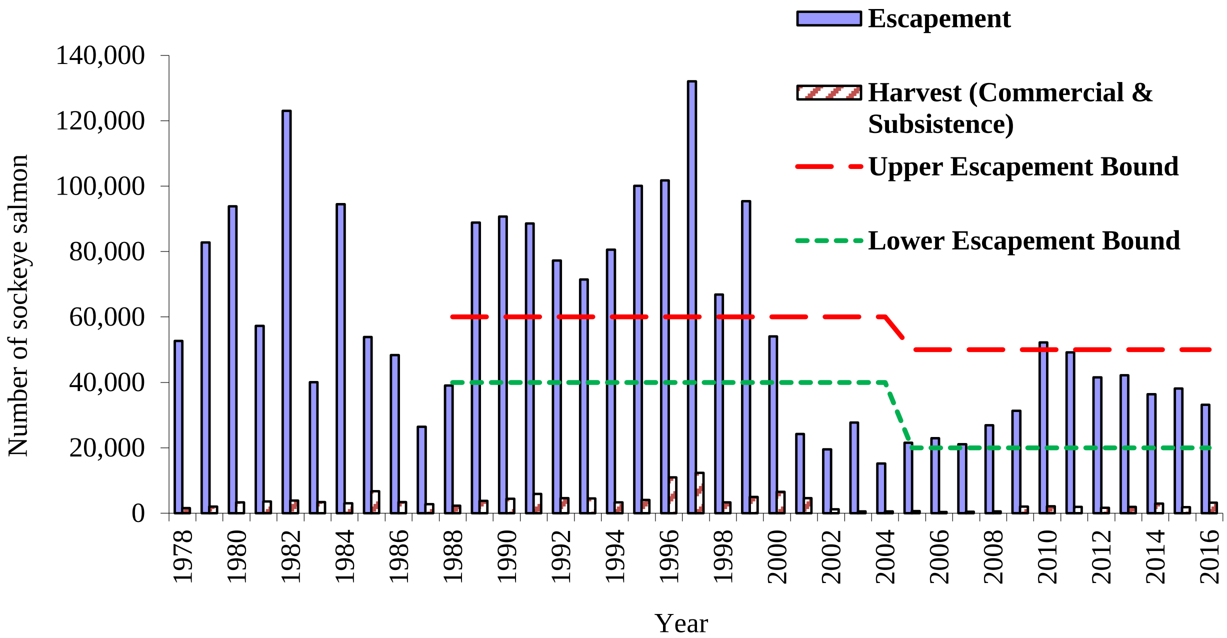

Figure 12.–Escapement and harvest of Afognak Lake sockeye salmon, 1978–2016.

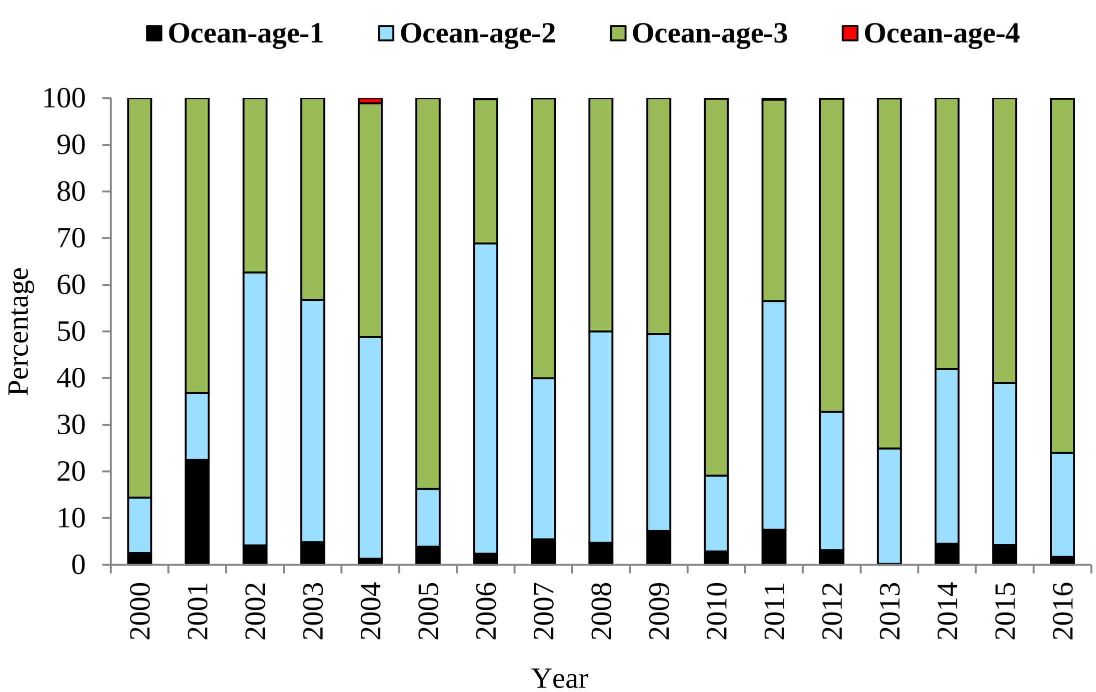

Figure 13.–Percentage of sockeye salmon escapement into Afognak Lake, by ocean age and year, 2000–2016.

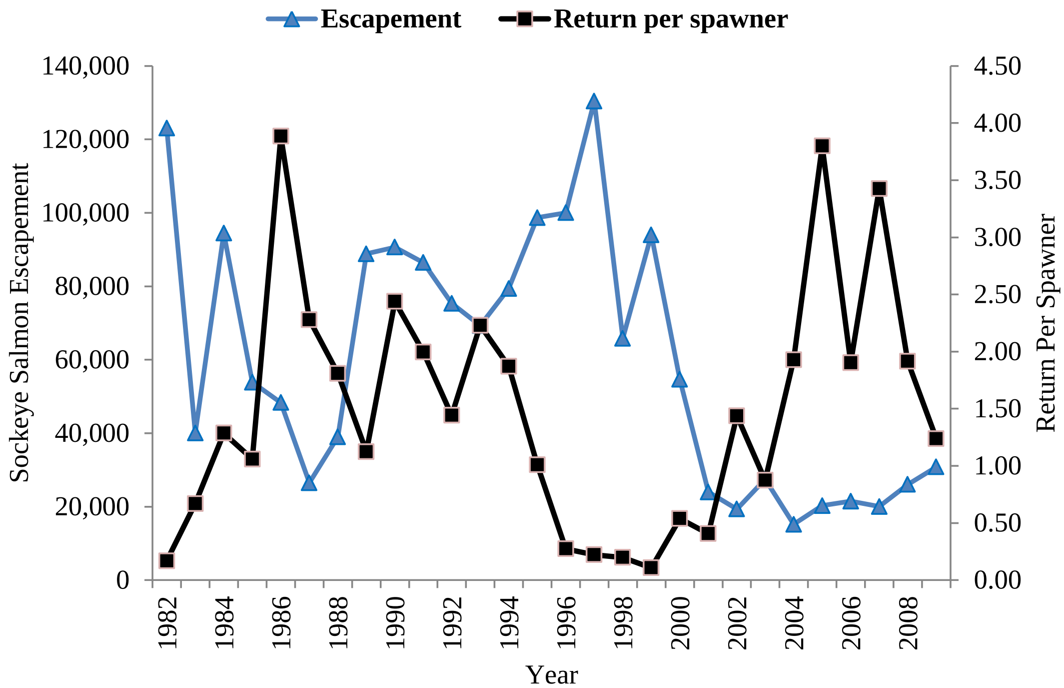

Figure 14.–Relationship between sockeye salmon escapement into Afognak Lake and return per spawner, 1982–2009.

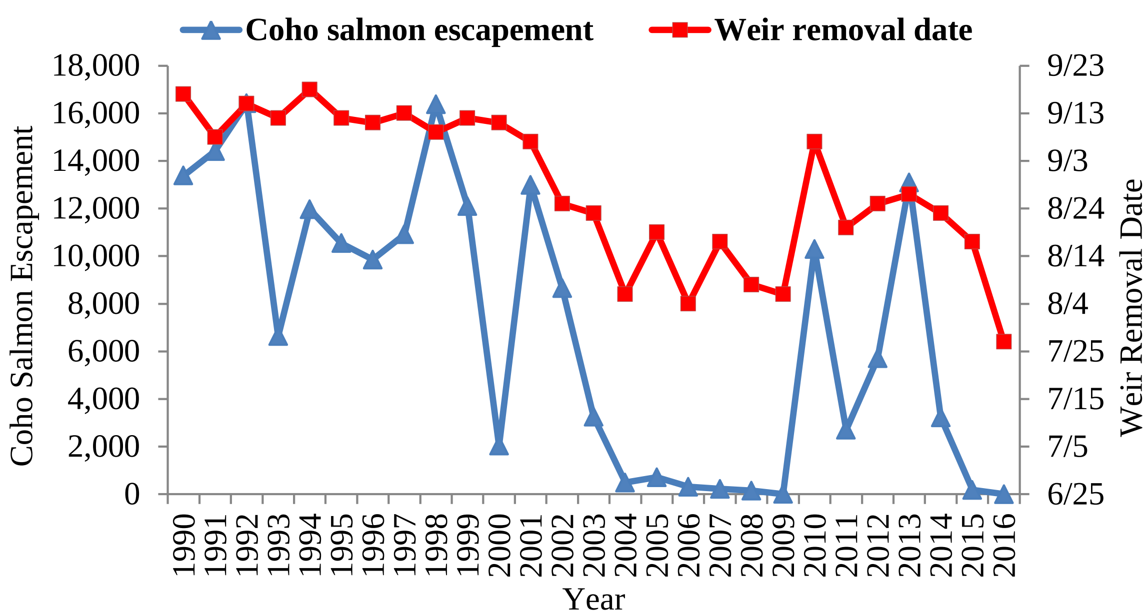

Figure 15.–Afognak Weir removal date compared to coho escapement by year, 1990–2016.

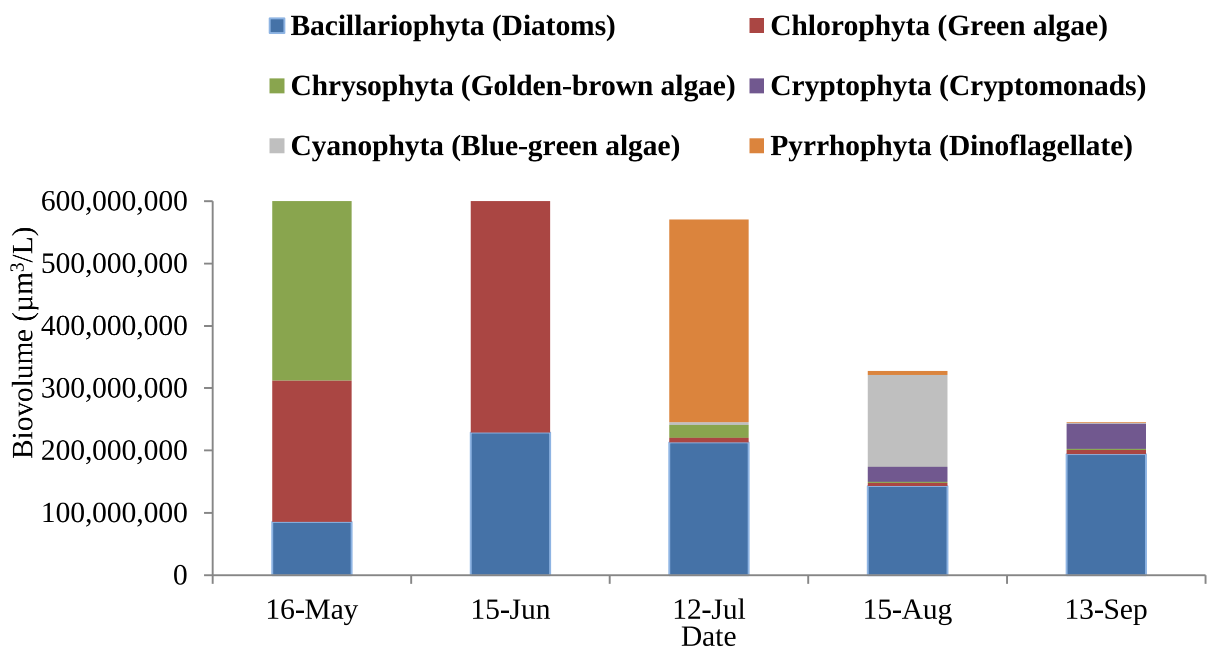

Figure 16.–Relative monthly biovolume and succession of Afognak Lake phytoplankton, by phylum, 2016.

APPENDIX A. SUPPORTING HISTORICAL INFORMATION

Appendix A1.–Population estimates of sockeye salmon smolt outmigrations from Afognak Lake 2003–2016.

Stratum	Starting	Ending	Catch	Released	Recaptured	Average trap	Estimate	Variance	95% confidence interval	
(h)	date	date	(u_h)	(M_h)	(m_h)	efficiency (%)	(U_h)	(U_h)	lower	upper
					2003					
1	5/12	5/19	1,387	239	5	2.1%	55,480	430,580,280	14,809	96,151
2	5/20	5/25	2,912	239	5	2.1%	116,480	1,893,665,280	31,188	201,772
3	5/26	5/31	11,966	706	161	22.8%	52,222	13,071,832	45,136	59,308
4	6/1	6/7	31,358	638	133	20.8%	149,536	131,461,163	127,063	172,008
5	6/8	6/10	11,153	686	257	37.5%	29,698	2,175,656	26,807	32,589
6	6/11	6/18	18,696	679	103	15.2%	122,243	121,222,146	100,663	143,823
7	6/19	6/26	4,762	506	79	15.6%	30,179	9,629,085	24,097	36,261
8	6/27	7/3	736	218	17	7.8%	8,955	3,968,174	5,050	12,859
Total			82,970	3,911	760	19.9%	564,793	2,605,773,616	374,814	754,772
								SE = 51,047		
					2004					
1	5/11	5/26	24,278	525	56	10.7%	224,039	773,437,348	169,530	278,548
2	5/27	6/3	17,727	547	96	17.6%	100,148	84,689,189	82,111	118,186
3	6/4	6/11	16,658	700	211	30.1%	55,081	10,062,676	48,864	61,299
4	6/12	6/19	5,086	613	119	19.4%	26,023	4,609,226	21,815	30,231
5	6/20	7/3	3,779	581	88	15.1%	24,712	5,883,161	19,958	29,466
Total			67,528	2,966	570	18.6%	430,004	878,681,600	371,905	488,104
								SE = 29,643		

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Stratum (h)	Starting date	Ending date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Average trap efficiency (%)	Estimate (U_h)	Variance (U_h)	95% confidence interval lower	upper
					2005					
1	5/10	5/21	27,226	489	70	14.3%	184,879	404,815,551	145,443	224,314
2	5/22	5/26	13,627	518	43	8.3%	155,259	488,664,939	111,932	198,587
3	5/27	6/5	15,210	482	44	9.1%	158,499	493,724,194	114,948	202,050
4	6/6	6/27	17,634	368	103	28.0%	61,593	25,786,901	51,640	71,546
Total			73,697	1,857	260	14.9%	560,230	1,412,991,585	486,554	633,906
								SE = 37,590		
					2006					
1	5/16	6/1	25,983	312	73	23.6%	110,017	123,618,701	88,224	131,809
2	6/2	6/6	8,199	515	98	19.2%	42,726	14,930,053	35,153	50,299
3	6/7	6/16	7,108	485	95	19.8%	35,975	10,850,929	29,519	42,432
4	6/17	6/29	2,534	492	75	15.4%	16,435	3,056,035	13,009	19,861
Total			43,824	1,804	341	19.5%	205,153	152,455,718	180,952	229,353
								SE = 12,347		
					2007					
1	5/10	6/5	14,450	415	51	12.5%	115,690	221,784,590	86,501	144,879
2	6/6	6/12	19,469	202	124	61.5%	31,680	3,089,891	28,235	35,125
3	6/13	6/20	15,281	510	82	16.2%	94,135	88,847,348	75,660	112,609
4	6/21	6/27	5,216	541	108	20.1%	25,914	4,978,154	21,541	30,288
5	6/28	7/4	899	401	44	11.2%	8,031	1,307,504	5,790	10,272
Total			55,315	2,070	409	19.9%	275,450	320,007,488	240,388	310,512
								SE = 17,889		

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Stratum (h)	Starting date	Ending date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Average trap efficiency (%)	Estimate (U_h)	Variance (U_h)	95% confidence interval lower	95% confidence interval upper
					2008					
1	5/16	5/31	6,516	202	44	21.2%	29,434	14,766,057	21,903	36,966
2	6/1	6/11	12,500	394	32	8.4%	149,621	605,011,907	101,411	197,831
3	6/12	6/19	2,559	244	53	22.0%	11,989	2,079,787	9,162	14,815
4	6/20	7/3	1,290	306	62	20.5%	5,896	454,235	4,575	7,217
Total			22,865	1,147	191	18.3%	196,941	622,311,987	148,046	245,835
								SE = 24,946		
					2009					
1	5/10	5/22	14,338	381	65	17.3%	82,891	85,202,787	64,799	100,983
2	5/23	6/1	37,537	356	50	14.3%	262,568	1,137,808,443	196,454	328,681
3	6/2	6/9	5,829	420	43	10.5%	55,727	62,257,984	40,261	71,192
4	6/10	6/21	5,753	425	35	8.5%	68,080	115,400,599	47,025	89,136
5	6/22	7/3	1,510	93	5	6.4%	23,732	75,639,388	6,686	40,778
Total			64,967	1,674	198	11.4%	492,998	1,476,309,201	417,689	568,306
								SE = 38,423		
					2010					
1	5/9	5/17	1,026	150	10	7.3%	14,090	15,502,483	6,373	21,807
2	5/18	5/24	788	385	28	7.5%	10,489	3,516,305	6,813	14,164
3	5/25	5/31	17,620	274	39	14.6%	120,961	305,577,452	86,699	155,224
4	6/1	6/7	10,687	275	50	18.5%	57,852	52,723,880	43,620	72,084
5	6/8	6/14	8,802	228	36	16.2%	54,477	65,755,815	38,584	70,371
6	6/15	6/21	2,566	464	27	6.0%	42,585	59,405,936	27,478	57,691
7	6/22	7/1	1,172	488	65	13.5%	8,677	1,026,613	6,691	10,663
Total			42,661	2,263	255	11.9%	309,130	443,075,935	267,874	350,387
								SE = 21,049		

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Stratum (h)	Starting date	Ending date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Average trap efficiency (%)	Estimate (U_h)	Variance (U_h)	95% confidence interval lower	upper
					2011					
1	5/9	6/5	29,701	511	84	16.6%	178,755	311,317,921	144,206	213,303
2	6/6	6/13	10,539	200	35	17.9%	58,843	77,082,015	41,635	76,051
3	6/14	6/20	9,567	462	70	15.3%	62,442	46,195,379	49,120	75,763
4	6/21	6/27	3,628	169	27	16.5%	21,979	14,015,319	14,641	29,317
5	6/28	7/6	974	300	36	12.3%	7,930	1,506,726	5,524	10,336
Total			54,409	1,642	252	15.7%	329,949	450,117,359	288,393	371,502
								SE = 21,201		
					2012					
1	5/8	6/1	5,197	350	69	20.0%	26,037	7,745,327	20,583	31,492
2	6/2	6/7	4,010	314	43	14.0%	28,744	15,972,827	20,911	36,578
3	6/8	6/15	7,933	347	78	22.7%	34,988	11,950,503	28,213	41,764
4	6/16	6/23	4,672	438	55	12.8%	36,632	20,785,598	27,696	45,568
5	6/24	6/28	280	463	88	19.2%	1,460	25,218	1,149	1,771
Total			22,092	1,913	333	17.7%	127,862	56,479,474	98,551	157,173
								SE = 7,515		
					2013					
1	5/8	5/26	10,123	201	38	19.3%	52,432	55,672,176	37,808	67,056
2	5/27	6/2	9,250	582	107	18.5%	49,933	18,854,409	41,422	58,444
3	6/3	6/10	8,167	282	22	8.1%	100,518	387,878,482	61,917	139,119
4	6/11	6/18	7,947	507	48	9.6%	82,438	123,574,935	60,650	104,226
5	6/19	6/27	1,419	319	22	7.2%	19,712	15,267,794	12,053	27,370
Total			36,906	1,891	237	12.6%	305,033	601,247,796	213,849	396,216
								SE = 24,520		

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Stratum (h)	Starting date	Ending date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Average trap efficiency (%)	Estimate (U_h)	Variance (U_h)	95% Confidence Interval lower	upper
					2014					
1	4/24	5/11	4,859	195	36	18.8%	25,777	14,298,284	18,366	33,189
2	5/12	5/18	3,767	525	36	7.0%	53,565	70,884,179	37,063	70,066
3	5/19	5/23	2,643	527	57	11.0%	24,062	8,927,203	18,206	29,918
4	5/24	6/5	6,834	332	33	10.2%	66,965	115,620,744	45,890	88,040
5	6/6	6/19	8,777	271	61	22.8%	38,566	18,364,650	30,167	46,966
6	6/20	6/26	791	234	19	8.5%	9,304	3,866,804	5,450	13,158
Total			27,671	2,085	242	13.1%	218,239	231,961,865	155,141	281,338
								SE = 15,230		
					2015					
1	4/22	5/19	3,076	166	39	23.9%	12,861	3,098,847	9,411	16,311
2	5/20	5/27	6,010	462	87	19.0%	31,621	9,232,489	25,666	37,576
3	5/28	6/4	4,479	477	83	17.6%	25,488	6,417,681	20,523	30,453
4	6/5	6/10	4,611	537	52	10.7%	43,069	36,994,076	31,148	54,990
5	6/11	6/19	1,510	554	36	7.3%	20,841	12,909,308	13,799	27,883
Total			19,686	2,196	297	15.7%	133,880	68,652,401	100,547	167,213
								SE = 8,286		

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Stratum (h)	Starting date	Ending date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Carlson trap efficiency (%)	Estimate (U_h)	Variance (U_h)	95% Confidence interval lower	95% Confidence interval upper
2016										
1	5/2	5/19	2,456	522	52	10.1%	24,414	9,985,805	18,219	30,607
2	5/20	5/24	3,554	546	47	9.1%	38,883	30,950,698	27,980	49,788
3	5/25	5/31	9,581	539	75	19.5%	49,052	1,233,192	34,901	63,203
4	6/1	6/6	17,277	548	150	29.3%	59,053	18,983,392	50,513	67,593
5	6/7	6/14	4,126	547	45	8.9%	48,824	47,615,054	35,299	62,349
6	6/15	6/23	1,531	504	108	22.0%	6,952	384,202	5,737	8,167
Total			38,525	3,206	477	16.5%	227,178	109,152,343	172,650	281,706
								SE = 12,651		
Average (2003–2015)			47,276			16.1%	319,205			
SD (2003–2015)			21,070			3.1%	150,645			
Average (2011–2015)			32,153			14.9%	222,992			
SD (2011–2015)			14,095			2.1%	93,787			

Appendix A2.–Mean and percentage composition by year of sockeye salmon smolt sampled from outmigrants at Afognak Lake, 2003–2016.

	Age						
Year	1	%	2	%	3	%	Total
2003	373,513	66.1%	191,279	33.9%	0	0.0%	564,793
2004	387,584	90.1%	42,420	9.9%	0	0.0%	430,004
2005	521,025	93.0%	39,205	7.0%	0	0.0%	560,230
2006	146,527	71.4%	58,626	28.6%	0	0.0%	205,153
2007	237,383	86.2%	38,067	13.8%	0	0.0%	275,450
2008	92,018	46.7%	104,923	53.3%	0	0.0%	196,941
2009	427,141	86.6%	64,560	13.1%	1,296	0.3%	492,998
2010	237,716	76.9%	71,415	23.1%	0	0.0%	309,130
2011	250,741	76.0%	79,207	24.0%	0	0.0%	329,948
2012	99,604	77.9%	28,257	22.1%	0	0.0%	127,861
2013	249,107	81.7%	55,630	18.2%	296	0.1%	305,033
2014	135,410	62.0%	82,830	38.0%	0	0.0%	218,239
2015	113,689	84.9%	20,191	15.1%	0	0.0%	133,880
2016	212,628	93.6%	14,550	6.4%	0	0.0%	227,178
Mean (2003–2015)	251,651	76.9%	67,432	23.1%	123	0.0%	319,205
Mean (2011–2015)	169,710	76.5%	53,223	23.5%	59	0.0%	222,992

Appendix A3.–Mean weight, length, and condition factor by age for sockeye salmon smolt sampled at Afognak Lake, 1987–2001 and 2003–2016.

		Age-1				Age-2			
Year	Sampling period	Sample size (n)	Weight (g)	Length (mm)	Condition (K)	Sample size (n)	Weight (g)	Length (mm)	Condition (K)
1987	8-Jun	36	3.6	74.9	0.85	186	3.6	79.3	0.86
1988	15-Jun	202	4.1	77.9	0.90	0	–	–	–
1989	15-Jun	208	4.1	76.8	0.91	2	5.2	78.0	1.10
1990	23 May–24 June	544	2.5	68.8	0.76	21	3.4	77.3	0.73
1991	13 May–26 June	1,895	3.1	72.9	0.78	176	3.9	78.3	0.81
1992	7 June–20 June	268	3.8	77.0	0.82	37	3.8	76.9	0.83
1993	24 May–30 May	274	3.0	72.7	0.78	21	3.3	74.8	0.79
1994	17 May–23 May	138	3.0	72.0	0.81	142	4.7	84.3	0.79
1995	31 May–13 June	394	2.8	69.4	0.84	5	3.6	78.8	0.74
1996	5 June–11 June	54	4.6	80.9	0.87	339	4.8	81.6	0.88
1997	24 May–30 May	76	4.3	81.7	0.78	122	4.4	82.1	0.79
1998	24 May–30 May	116	2.6	66.4	0.82	46	6.6	88.0	0.90
1999	31 May–6 June	96	2.8	74.6	0.66	98	2.1	66.6	0.69
2000	31 May–13 June	84	4.9	81.5	0.89	100	5.6	85.3	0.89
2001	11 June–13 June	44	7.0	90.1	0.93	17	5.8	85.6	0.92
2003	12 May–3 July	1,031	4.2	79.1	0.82	383	4.2	81.4	0.77
2004	11 May–3 July	1,370	3.6	75.7	0.80	81	3.6	78.7	0.74
2005	10 May–27 June	1,248	3.9	76.8	0.84	65	4.2	81.3	0.77
2006	16 May–29 June	765	3.0	70.8	0.83	202	3.8	79.6	0.75
2007	21 May–2 July	960	2.6	70.4	0.75	129	3.4	76.5	0.74
2008	26 May–28 June	169	3.4	75.9	0.76	164	4.0	81.7	0.73
2009	13 May–29 June	1,053	3.5	76.7	0.76	205	5.3	88.8	0.75
2010	9 May–1 July	601	2.6	69.9	0.76	198	3.9	82.1	0.69
2011	9 May–6 July	757	3.1	71.8	0.81	128	3.7	78.4	0.77
2012	8 May–28 June	378	3.1	72.5	0.81	134	3.9	79.1	0.78
2013	8 May–27 June	534	3.8	76.6	0.84	220	4.7	84.2	0.79
2014	7 May–26 June	353	3.5	74.0	0.83	160	4.1	80.6	0.78
2015	21 April–19 June	286	3.0	72.1	0.81	74	3.6	78.3	0.74
2016	22 May–23 June	1,119	4.7	81.4	0.85	90	4.0	80.1	0.76
Average (1987–2015)		498	3.6	75.0	0.82	123	4.2	80.3	0.80
Average (2006–2015)		586	3.2	73.1	0.80	161	4.0	80.9	0.75
Average (2011–2015)		462	3.3	73.4	0.82	143	4.0	80.1	0.77

Appendix A4.–Estimated age composition of the Afognak Lake sockeye salmon escapement, 1985–2016.

			Ages								
Year	Sample size (*n*)		1.1	1.2	2.1	1.3	2.2	1.4	2.3	3.2	Total[a]
1985	691	Percent	0.0	26.0	0.0	51.1	14.1	0.4	8.4	0.0	100.0
		Numbers	15	14,027	0	27,506	7,593	206	4,525	0	53,872
1986	484	Percent	0.6	10.1	0.2	74.8	5.8	0.2	8.1	0.0	100.0
		Numbers	300	4,893	100	36,150	2,796	100	3,895	0	48,333
1987	647	Percent	5.2	32.2	1.0	45.3	2.5	0.0	13.8	0.0	100.0
		Numbers	1,376	8,513	257	11,992	660	0	3,645	0	26,474
1988	933	Percent	0.7	59.5	3.2	24.2	11.2	0.0	0.9	0.0	100.0
		Numbers	257	23,227	1,233	9,441	4,363	0	350	0	39,012
1989	543	Percent	8.7	11.4	3.1	50.8	24.1	0.0	1.8	0.0	100.0
		Numbers	7,688	10,142	2,781	45,149	21,429	0	1,636	0	88,825
1990	1,053	Percent	0.7	46.7	0.6	22.6	8.6	0.3	20.5	0.0	100.0
		Numbers	598	42,314	554	20,518	7,754	262	18,614	0	90,666
1991	1,062	Percent	0.3	14.7	0.2	76.6	3.5	0.0	4.6	0.0	100.0
		Numbers	295	13,055	195	67,808	3,099	0	4,105	0	88,557
1992	1,025	Percent	21.2	22.2	9.9	29.9	3.8	0.5	12.3	0.0	100.0
		Numbers	16,360	17,114	7,680	23,096	2,938	394	9,527	0	77,260
1993	852	Percent	16.6	10.7	17.2	30.3	12.3	0.0	12.5	0.2	100.0
		Numbers	11,838	7,634	12,318	21,676	8,815	0	8,965	162	71,460
1994	840	Percent	9.6	30.6	4.1	35.2	10.3	0.1	9.6	0.1	100.0
		Numbers	7,703	24,648	3,337	28,387	8,315	62	7,707	64	80,570
1995	848	Percent	2.3	21.8	0.8	56.3	10.8	0.1	7.8	0.0	100.0
		Numbers	2,282	21,786	838	56,366	10,773	147	7,778	0	100,131
1996	1,119	Percent	16.1	9.2	2.1	44.0	2.1	0.2	26.0	0.1	100.0
		Numbers	16,339	9,398	2,183	44,744	2,094	184	26,428	81	101,718

[a] Totals include some age classes not listed.

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Appendix A4.–Page 2 of 3.

Year	Sample size (*n*)		Ages 1.1	1.2	2.1	1.3	2.2	1.4	2.3	3.2	Total[a]
1997	1,168	Percent	5.1	25.9	6.6	45.8	2.0	0.0	14.6	0.0	100.0
		Numbers	6,704	34,145	8,697	60,416	2,632	41	19,247	0	132,050
1998	1,240	Percent	19.0	8.0	7.1	49.1	10.6	0.4	5.5	0.0	100.0
		Numbers	12,720	5,371	4,767	32,826	7,099	250	3,684	0	66,869
1999	1,195	Percent	1.1	38.8	0.5	9.5	42.7	0.2	6.6	0.5	100.0
		Numbers	1,030	36,992	506	9,043	40,720	232	6,278	455	95,361
2000	1,161	Percent	2.1	2.5	0.3	15.7	6.0	0.0	69.1	3.3	100.0
		Numbers	1,121	1,348	188	8,484	3,228	0	37,382	1,806	54,064
2001	790	Percent	1.4	11.0	6.2	23.4	3.2	0.0	39.3	0.0	100.0
		Numbers	334	2,681	1,496	5,683	775	0	9,540	0	24,271
2002	238	Percent	0.1	1.0	3.2	32.6	24.7	0.0	4.8	32.8	100.0
		Numbers	19	194	625	6,358	4,830	0	935	6,399	19,520
2003	498	Percent	4.1	22.6	0.2	0.8	25.7	0.0	29.6	2.8	100.0
		Numbers	1,148	6,273	66	233	7,141	0	8,229	770	27,766
2004	566	Percent	1.1	44.3	0.2	19.0	1.8	0.0	26.8	0.0	100.0
		Numbers	170	6,720	25	2,888	280	3	4,073	0	15,181
2005	572	Percent	3.2	10.0	0.6	82.0	2.2	0.0	1.3	0.0	100.0
		Numbers	683	2,153	136	17,697	472	0	280	0	21,577
2006	613	Percent	2.5	63.1	0.0	22.1	2.6	0.0	9.4	0.0	100.0
		Numbers	569	14,481	0	5,075	596	36	2,156	0	22,933
2007	590	Percent	5.1	32.5	0.3	54.4	2.1	0.0	5.6	0.0	100.0
		Numbers	1,076	6,844	67	11,461	436	8	1,178	0	21,070
2008	643	Percent	4.3	41.6	0.3	49.4	3.7	0.0	0.6	0.0	100
		Numbers	1,165	11,177	87	13,269	1,003	0	173	0	26,874

[a] Totals include some age classes not listed.

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			Ages								
Year	Sample size (*n*)		1.1	1.2	2.1	1.3	2.2	1.4	2.3	3.2	Total[a]
2009	776	Percent	4.5	39.9	2.7	47.7	2.3	0.0	2.8	0.0	100
		Numbers	1,412	12,520	852	14,969	722	0	884	0	31,358
2010	954	Percent	2.6	15.8	0.2	80.6	0.5	0.1	0.2	0.0	100
		Numbers	1,377	8,234	103	42,108	267	52	114	0	52,255
2011	750	Percent	4.2	40.2	3.3	28.5	8.8	0.3	14.7	0.0	100
		Numbers	2,086	19,771	1,606	14,015	4,340	152	7,222	0	49,193
2012	767	Percent	2.3	15.7	0.8	56.7	14.0	0.1	10.4	0.0	100
		Numbers	968	6,531	325	23,565	5,800	48	4,315	0	41,553
2013	747	Percent	0.2	19.6	0.0	63.9	5.1	0.0	11.1	0.0	100
		Numbers	78	8,269	0	26,939	2,169	17	4,682	0	42,153
2014	570	Percent	3.8	23.0	0.7	44.7	14.3	0.0	13.4	0.0	100
		Numbers	1,373	8,365	245	16,230	5,204	0	4,874	0	36,345
2015	583	Percent	2.9	30.0	1.4	45.8	4.6	0.0	15.3	0.0	100
		Numbers	1,089	11,464	521	17,474	1,764	0	5,839	0	38,151
2016	1,772	Percent	1.9	11.6	0.0	57.6	10.9	0.1	17.8	0.0	100
		Numbers	616	3,835	0	19,098	3,627	26	5,891	0	33,167
Average (1985–2015)		Percent	4.9	25.2	2.5	42.3	9.2	0.1	13.1	1.3	
All years		Numbers	3,130	12,509	1,618	22,549	5,316	69	6,821	304	52,669
Average (2006–2015)		Percent	3.2	32.1	1.0	49.4	5.8	0.1	8.4	0.0	
10-yr average		Numbers	1,119	10,766	381	18,511	2,230	31	3,144	0	36,189
Average (2011–2015)		Percent	2.7	25.7	1.2	47.9	9.4	0.1	13.0	0.0	
5-yr average		Numbers	1,119	10,880	540	19,645	3,855	43	5,386	0	41,479

[a] Totals include some age classes not listed.

Appendix A5.–Afognak Weir cumulative escapement counts by year and species, 1990–2016.

Year	Sockeye	Chinook	Pink	Coho	Chum	Steelhead down	Steelhead up	All species
1990	90,666	0	27,808	13,380	0	191	61	132,106
1991	88,557	0	13,985	14,409	0	392	24	117,367
1992	77,260	0	28,945	16,415	0	202	34	122,856
1993	71,460	2	21,830	6,637	0	173	44	100,146
1994	80,570	5	49,756	11,965	8	356	11	142,671
1995	100,131	3	42,738	10,542	0	335	46	153,795
1996	101,718	0	11,307	9,856	14	154	103	123,152
1997	132,050	1	19,122	10,908	4	563	8	162,656
1998	66,869	3	101,177	16,374	14	150	78	184,665
1999	95,361	8	30,959	12,092	11	783	31	139,245
2000	54,064	8	67,003	2,036	8	185	18	123,322
2001	24,271	1	25,228	12,981	6	118	4	62,609
2002	19,520	1	76,242	8,654	3	67	0	104,487
2003	27,766	1	34,330	3,256	13	221	1	65,588
2004	15,181	2	9,563	492	40	63	3	25,344
2005	21,577	2	41,594	715	0	59	0	63,947
2006	22,933	4	9,235	312	11	80	0	32,575
2007	21,070	0	11,777	225	9	309	1	33,391
2008	26,874	0	15,716	147	1	316	0	43,054
2009	31,358	0	895	13	6	383	1	32,656
2010	52,255	1	62,237	10,288	59	256	1	125,097
2011	49,193	0	4,241	2,700	4	128	0	56,266
2012	41,553	1	111,928	5,701	5	91	0	159,279
2013	42,153	1	17,400	13,090	1	78	0	64,723
2014	36,345	1	18,408	3,224	0	85	10	58,063
2015	38,151	0	3,203	181	2	70	2	41,609
2016	33,167	0	0	4	6	11	0	33,188
Average fertilization yrs. (1990–2000)	87,155	3	37,694	11,329	5	317	42	136,544
Average all years (1990–2015)	54,958	2	32,947	7,177	8	223	19	95,026
10-year average (2006–2015)	36,189	1	25,504	3,588	10	180	2	64,671
5-year average (2011–2015)	41,479	1	31,036	4,979	2	90	2	75,988

Appendix A6.–Temperatures (°C) measured at the 1-meter and near-bottom strata at station 1 in the spring (May–June), summer (July–August), and fall (September–October) for Afognak Lake, 1989–2016.

	Spring		Summer		Fall	
Year	Surface	Bottom	Surface	Bottom	Surface	Bottom
1989	7.8	7.0	16.6	12.5	16.0	16.0
1990	6.8	6.5	15.2	13.9	12.0	11.5
1991	6.0	5.1	15.2	13.2	12.4	12.2
1992	10.0	8.6	15.5	13.8	11.3	11.0
1993	12.0	10.5	16.5	10.2	13.5	12.8
1994	10.9	8.9	15.4	13.7	10.2	10.1
1995	9.1	7.6	15.2	13.5	12.5	12.2
1996	11.8	9.7	15.5	13.8	11.1	11.0
1997	10.5	7.2	17.3	9.9	11.8	11.6
1998	7.9	7.8	14.3	13.0	11.8	11.6
1999	7.0	6.2	15.1	11.4	10.4	10.1
2000	9.7	8.7	15.0	13.1	10.1	10.0
2001	9.1	7.0	17.1	10.2	12.9	12.5
2002	10.0	7.9	16.0	10.8	9.3	9.2
2003	9.7	9.3	18.3	12.9	11.5	11.3
2004	9.2	8.2	13.8	9.8	13.1	12.9
2005	11.8	10.5	18.2	12.9	13.6	13.4
2006	9.2	7.9	15.8	12.5	12.6	12.5
2007	9.2	6.7	15.5	9.3	12.4	12.2
2008	8.4	6.9	15.2	13.3	11.8	11.7
2009	11.3	6.9	17.3	13.6	12.4	12.3
2010	8.8	8.1	15.1	13.6	14.3	14.1
2011	8.3	7.5	14.7	11.8	12.1	11.9
2012	10.3	7.7	14.4	12.4	11.8	11.9
2013	10.4	7.8	17.2	13.1	13.3	13.0
2014	11.9	10.7	16.1	13.7	14.8	14.7
2015	11.7	9.5	16.9	12.7	13.1	13.2
2016	13.3	11.0	17.6	14.5	16.7	16.4
Avgerage (1989–2015)	9.6	8.0	15.9	12.4	12.3	12.1
Average (2006-2015)	9.9	7.9	15.8	12.6	12.9	12.8
Average (2011–2015)	10.5	8.6	15.9	12.7	13.0	12.9

Appendix A7.–Dissolved oxygen concentrations (mg/L) measured at the 1-meter and near-bottom strata at station 1 in the spring (May–June), summer (July–August), and fall (September–October) for Afognak Lake, 1989–2016.

	Spring		Summer		Fall	
Year	Surface	Bottom	Surface	Bottom	Surface	Bottom
1989	11.7	11.3	11.1	8.1	12.1	10.6
1990	12.6	9.5	9.4	7.8	9.3	8.6
1991	12.3	11.4	10.3	8.5	9.9	9.7
1992	11.6	11.1	10.1	8.8	10.8	10.8
1993	10.7	10.0	9.4	6.8	10.5	10.1
1994	10.9	9.1	10.0	7.9	11.0	10.9
1995	11.4	11.9	9.4	8.2	10.3	9.5
1996	11.0	10.4	10.0	6.9	11.0	10.7
1997	11.1	10.9	9.2	4.3	10.3	9.2
1998	11.8	11.7	10.2	6.1	10.2	10.0
1999	11.9	11.5	9.6	6.2	10.9	10.4
2000	11.0	9.1	9.7	6.8	10.5	10.1
2001	9.7	9.6	9.3	4.7	9.0	8.1
2002	10.8	9.3	9.8	7.1	10.5	10.1
2003	12.0	11.2	9.2	5.5	10.0	10.3
2004	12.9	11.9	12.8	8.3	10.5	6.4
2005	10.8	10.1	9.4	5.0	9.4	8.5
2006	10.9	9.2	9.7	8.1	10.6	10.1
2007	11.3	10.4	9.5	6.6	10.5	9.5
2008	9.9	10.1	9.0	8.4	9.1	9.7
2009	10.6	10.1	9.3	7.7	8.8	8.3
2010	9.8	9.2	9.8	8.9	10.0	9.6
2011	12.3	11.9	10.2	7.7	10.2	9.6
2012	12.1	11.8	10.7	9.8	11.0	10.6
2013	12.2	11.9	9.9	7.6	10.0	9.7
2014	10.9	10.5	8.9	6.5	8.9	8.6
2015	11.5	11.0	9.7	6.4	10.1	9.8
2016	11.4	10.7	9.9	8.2	9.7	9.1
Average (1989–2015)	11.3	10.6	9.8	7.2	10.2	9.6
Average (2006–2015)	11.1	10.6	9.7	7.7	9.9	9.5
Average (2011–2015)	11.8	11.4	9.9	7.6	10.0	9.7

Appendix A8.–Average euphotic zone depth (EZD), light extinction coefficient (K_d), Secchi disk transparency, and euphotic volume (EV) for Afognak Lake, 1989–2016.

Year	EZD (m)	SD	K_d (m^{-1})	SD	Secchi (m)	SD	EV ($10^6 m^3$)	SD
1987	8.43	1.14	NA	NA	4.7	1.4	44.65	6.04
1988	11.91	2.78	NA	NA	4.2	0.5	63.14	14.73
1989	13.05	3.53	-0.39	0.08	4.75	0.28	69.16	18.68
1990	9.31	3.04	-0.55	0.25	3.64	0.63	49.35	16.12
1991	10.41	3.10	-0.49	0.18	2.76	0.39	55.19	16.44
1992	10.54	2.15	-0.45	0.08	2.80	0.92	55.87	11.39
1993	9.40	3.13	-0.58	0.31	3.51	0.53	49.82	16.60
1994	7.40	1.51	-0.61	0.11	3.39	0.35	39.23	8.03
1995	7.39	1.33	-0.61	0.12	2.45	0.54	39.17	7.06
1996	7.95	1.69	-0.58	0.14	3.52	0.41	42.14	8.97
1997	8.47	1.32	-0.56	0.12	3.24	0.74	44.90	7.00
1998	7.36	0.95	-0.60	0.09	3.75	1.21	39.01	5.01
1999	8.93	2.79	-0.56	0.11	2.94	0.55	47.31	14.79
2000	9.81	1.60	-0.46	0.07	3.38	0.67	52.00	8.48
2001	11.04	3.35	-0.46	0.12	3.95	1.14	58.50	17.75
2002	10.51	0.57	-0.41	0.02	4.25	0.54	55.72	3.03
2003	9.80	1.31	-0.44	0.06	4.50	0.23	51.92	6.94
2004	10.19	2.99	-0.46	0.08	4.10	0.49	54.00	15.86
2005	9.55	0.71	-0.46	0.05	4.83	0.63	50.63	3.77
2006	9.03	1.01	-0.49	0.07	4.04	0.71	47.87	5.35
2007	9.44	1.17	-0.49	0.08	4.10	0.66	50.05	6.22
2008	9.07	1.47	-0.51	0.08	4.33	0.35	48.06	7.82
2009	9.36	0.41	-0.48	0.03	4.40	0.72	49.63	2.19
2010	10.03	1.29	-0.44	0.06	4.50	0.80	53.13	6.83
2011	8.14	1.09	-0.55	0.08	4.25	0.59	43.16	5.77
2012	9.73	0.51	-0.45	0.03	4.98	0.45	51.56	2.69
2013	8.67	0.96	-0.52	0.06	4.75	0.60	45.96	5.09
2014	7.87	0.75	-0.56	0.06	4.15	0.44	41.74	3.99
2015	7.56	0.87	-0.61	0.08	4.28	0.64	40.08	4.62
2016	7.41	0.46	-0.60	0.05	4.15	0.47	39.29	2.43
Average (1987–2015)	9.32	1.67	-0.51	0.10	3.94	0.62	49.41	8.87
Average (2006–2015)	8.89	0.95	-0.51	0.06	4.38	0.60	47.12	5.06
Average (2011–2015)	8.40	0.84	-0.54	0.06	4.48	0.54	44.50	4.43

Note: Values are updated to reflect current database calculations. SD = standard deviation.

Appendix A9.–Summary of seasonal mean water chemistry parameters by station and depth for Afognak Lake, 1987–2016.

		Depth	Sp. conductivity		pH		Alkalinity		Turbidity		Color		Calcium		Magnesium		Iron	
Year	Station	(m)	(µmhos cm)	SD	(Units)	SD	(mg/L)	SD	(NTU)	SD	(Pt units)	SD	(mg/L)	SD	(mg/L)	SD	(µg/L)	SD
1987	1	1	47	2.6	6.7	0.2	10.0	0.8	0.8	0.3	8	1.7	3.6	0	0.6	0	76	34.9
	1	17	46	2.8	6.7	0.4	9.5	1.0	0.7	0.4	8	2.6	4	0	1.0	0	58	17.3
1988	1	1	51	5.9	6.7	0.5	10.8	1.3	1.4	1.0	12	2.4	4.7	ND	1.6	ND	50	13.6
	1	15	50	0.5	6.9	0.2	11.3	1.0	1.1	0.8	10	1.3	ND	ND	ND	ND	81	77.7
	2	1	51	3.7	6.9	0.1	10.5	1.7	1.4	1.1	12	3.2	ND	ND	ND	ND	63	22.3
	2	10	50	2.3	6.8	0.1	10.3	0.6	1.5	1.2	9	2.9	ND	ND	ND	ND	96	52.7
1989	1	1	64	1.9	7.0	0.5	10.6	1.5	2.4	3.5	8	4.4	4.0	0.6	1.1	0.9	44	10.5
	1	15	63	1.0	6.9	0.2	10.2	1.6	0.7	0.1	10	0.7	4.3	0.2	1.2	0.8	51	19.3
	2	1	63	0.8	7.0	0.3	10.4	1.3	0.8	0.2	10	1.1	3.8	0.4	1.5	0.6	53	9.1
	2	12	65	3.3	6.9	0.4	10.6	2.2	0.8	0.2	10	1.4	4.4	0.1	1.4	0.3	91	39.1
1990	1	1	41	1.7	6.8	0.1	6.3	0.5	0.8	0.4	14	3.4	2.9	1.4	0.4	0.3	121	24.3
	1	16	41	1.0	6.7	0.2	6.1	0.6	0.7	0.4	11	2.2	3.2	1.8	0.4	0.3	128	38.7
1991	1	1	38	0.8	6.7	0.1	10.4	7.8	0.9	0.3	13	0.8	2.1	0.3	0.8	0.5	210	31.1
	1	14	38	1.0	6.6	0.2	6.9	0.3	0.9	0.2	16	3.9	1.9	0.1	0.8	0.5	190	45.0
1992	1	1	35	1.2	6.6	0.2	5.8	1.0	0.9	0.5	12	3.4	2.5	0.9	0.6	0.3	157	9.3
	1	24	35	0.5	6.3	0.1	4.9	1.0	0.8	0.6	11	1.5	2.5	1.2	0.6	0.3	162	56.9
1993	1	1	37	1.0	6.6	0.1	7.5	2.7	0.5	0.1	7	7.5	2.2	0.4	1.3	1.1	104	34.9
	1	25	39	4.0	6.4	0.4	7.8	2.1	0.5	0.2	10	10.7	2.6	0.9	0.8	0.1	134	52.0
1994	1	1	39	6.5	6.6	0.2	6.2	2.0	1.1	0.8	5	3.2	2.2	0.9	0.6	0.2	141	44.0
	1	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1	26	36	0.9	6.3	0.3	6.5	2.5	0.7	0.3	6	4.7	2.2	0.5	0.6	0.2	197	87.7
1995	1	1	60	5.6	6.6	0.2	9.8	1.0	2.0	0.8	11	2.6	3.7	1.4	1.3	0.4	85	45.6
	1	17	60	5.4	6.5	0.2	10.0	1.3	2.3	1.2	9	2.0	3.4	0.5	1.6	0.5	101	33.0
	2	1	58	4.9	6.6	0.2	9.7	1.1	1.9	0.9	11	4.3	3.2	0.3	1.1	0.3	87	55.9
	2	11	58	4.3	6.5	0.2	9.6	1.1	2.0	0.8	10	5.5	3.5	0.4	1.3	0.3	101	53.9
1996	1	1	56	1.5	6.7	0.2	10.5	0.7	1.4	1.0	10	2.5	3.2	0.5	1.3	0.2	54	25.9
	1	18	57	2.7	6.6	0.1	11.2	1.9	1.5	0.7	9	0.5	3.1	0.5	1.1	0.3	72	33.2
	2	1	56	1.4	6.7	0.1	10.7	1.0	1.2	0.6	9	1.3	3.1	0.5	1.1	0.3	54	25.7
	2	11	57	1.1	6.7	0.1	10.7	1.0	1.5	0.6	11	2.6	2.9	0.5	1.5	0.3	89	43.4

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Year	Station	Depth (m)	Sp. Conductivity (µmhos cm)	SD	pH (Units)	SD	Alkalinity (mg/L)	SD	Turbidity (NTU)	SD	Color (Pt units)	SD	Calcium (mg/L)	SD	Magnesium (mg/L)	SD	Iron (µg/L)	SD
1997	1	1	53	0.6	7.1	0.2	12.1	1.6	1.1	0.1	9	1.9	3.1	0.4	1.1	0.3	28	16.6
	1	18	58	6.7	6.8	0.2	13.9	3.5	1.7	0.4	10	0.8	2.9	0.5	1.7	1.1	68	37.7
	2	1	53	0.8	7.1	0.1	11.7	0.5	1.0	0.2	11	3.8	3.0	0.3	1.0	0.3	34	17.3
	2	13	53	0.5	7.0	0.1	11.9	0.3	1.3	0.5	10	3.0	2.9	0.3	1.0	0.3	44	25.8
1998	1	1	49	0.6	7.0	0.1	12.6	1.3	1.7	1.2	18	10.7	3.2	0.5	0.8	0.2	26	15.0
	2	18	48	ND	7.0	ND	11.8	ND	2.0	ND	11	ND	3.3	ND	1.0	ND	48	ND
1999	1	1	58	0.0	6.8	0.2	11.1	0.6	1.6	1.0	11	1.7	3.3	0.3	1.4	0.1	82	43.8
2000	1	1	ND	ND	7.1	0.2	8.7	2.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2001	1	1	ND	ND	7.2	0.4	10.1	2.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2002	1	1	ND	ND	7.2	0.5	10.1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2003	1	1	ND	ND	6.9	0.1	9.8	0.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2004	1	1	ND	ND	6.9	0.1	11.4	0.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	2	18	ND	ND	6.8	0.1	10.9	0.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2005	1	1	ND	ND	6.8	0.1	10.9	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2006	1	1	ND	ND	6.8	0.1	11.3	0.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2007	1	1	ND	ND	6.8	0.1	10.9	1.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2008	1	1	ND	ND	6.7	0.2	11.4	1.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2009	1	1	ND	ND	7.0	0.4	11.7	0.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2010	1	1	ND	ND	7.2	0.1	9.5	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2011	1	1	ND	ND	7.4	0.1	11.3	1.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2012	1	1	ND	ND	7.5	0.2	11.1	0.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2013	1	1	ND	ND	7.4	0.1	11.9	0.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2014	1	1	ND	ND	7.5	0.1	11.4	0.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2015	1	1	ND	ND	7.5	0.1	9.6	2.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2016	1	1	ND	ND	7.8	0.1	10.2	1.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pre-fertilization yrs. (1987–1989)		1	55	3.0	6.8	0.3	10.5	1.3	1.3	1.2	9.8	2.6	4.0	0.3	1.2	0.5	57.2	18.1
Fertilization yrs. (1990–2000)		1	49	2.1	6.8	0.2	9.5	1.7	1.2	0.6	10.7	3.6	2.9	0.6	1.0	0.3	90.8	30.0
All yrs. (1987–2015)		1	50	2.3	6.9	0.2	10.2	1.4	1.3	0.8	10.4	3.3	3.2	0.6	1.0	0.4	81.4	26.7
Post-fertilization yrs. (2001–2015)		1	ND	ND	7.1	0.2	10.8	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5-yr (2011–2015)		1	ND	ND	7.4	0.1	11.1	1.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Note: NTU = Nephelometric Turbidity Scale. PT units = Platinum-Cobalt Scale.

Appendix A10.–Summary of seasonal mean nutrient and algal pigment concentrations by station and depth for Afognak Lake, 1987–2016.

	Station	Depth	Total Phosphorus		Total filterable-P		Filterable reactive-P		Total Kjeldahl Nitrogen		Ammonia		Nitrate +Nitrite		Reactive Silicon		Chlorophyll *a*		Phaeophytin *a*	
Year		(m)	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD
1987	1	1	8.8	3.6	3.1	1.5	1.6	0.3	130.5	5.6	4.8	2.6	134.7	57.8	3,255	719.8	0.64	0.21	0.54	0.19
	1	17	6.7	1.0	2.8	0.6	1.4	0.2	116.3	14.5	12.8	11.7	147.7	51.6	3,313	706.9	0.32	0.21	0.41	0.02
1988	1	1	8.1	2.2	4.7	1.9	2.7	0.6	140.2	18.9	4.2	2.0	60.4	36.0	2,509	344.9	1.64	1.02	0.74	0.17
	1	15	7.8	1.2	4.1	0.8	2.6	0.1	123.9	10.6	7.1	6.3	66.9	32.9	2,528	200.4	2.13	3.17	0.99	0.83
	2	1	8.0	2.8	5.7	4.4	3.1	0.8	127.6	17.6	3.5	1.9	60.2	31.3	2,602	134.1	1.58	1.22	0.72	0.33
	2	10	7.9	2.3	3.5	1.6	2.3	0.1	132.5	9.6	8.0	5.7	53.8	13.2	2,499	107.6	2.76	3.50	1.02	0.32
1989	1	1	8.3	2.8	4.2	0.6	2.4	0.4	138.9	17.8	2.6	3.4	67.2	47.0	2,714	197.7	0.92	0.39	0.54	0.17
	1	15	6.5	0.7	3.9	0.5	2.5	0.2	133.6	11.1	9.2	10.8	76.8	32.3	2,803	150.6	0.65	0.34	0.51	0.26
	2	1	7.1	1.6	4.2	0.7	2.8	0.5	125.9	10.0	3.0	4.1	69.9	45.6	2,752	209.4	0.75	0.18	0.41	0.18
	2	12	8.8	4.5	4.8	2.1	2.5	0.3	130.7	30.4	13.1	16.0	76.9	40.9	2,813	161.1	0.67	0.20	0.51	0.22
1990	1	1	4.5	1.5	2.9	4.2	3.7	1.7	128.0	16.5	8.0	3.0	40.3	29.1	3,250	247.5	0.34	0.19	0.17	0.03
	1	16	5.1	2.3	1.3	1.3	2.8	1.1	117.7	22.7	9.7	4.2	65.0	29.1	3,390	154.5	0.21	0.03	0.28	0.07
1991	1	1	5.0	2.8	3.2	0.6	2.3	0.4	150.6	22.6	11.5	1.8	56.8	21.3	2,865	108.6	0.31	0.21	0.27	0.07
	1	14	4.6	1.5	6.0	3.5	4.5	3.2	138.3	12.3	13.6	5.0	69.7	23.2	2,966	156.3	0.22	0.14	0.22	0.08
1992	1	1	3.8	0.5	4.1	2.5	3.1	2.4	135.0	13.9	3.3	1.7	61.7	26.1	3,163	158.9	0.44	0.29	0.28	0.13
	1	24	3.9	1.7	4.0	3.2	2.6	1.7	127.4	12.8	9.6	4.1	92.8	23.1	3,182	198.0	0.31	0.25	0.28	0.12
1993	1	1	4.5	0.8	3.7	1.3	2.8	0.5	148.0	18.5	5.0	2.2	49.1	30.4	3,132	220.6	1.01	0.31	0.36	0.03
	1	25	4.9	1.3	8.5	11.7	6.8	9.9	136.2	17.3	19.4	10.1	98.4	31.7	3,380	244.0	0.52	0.21	0.45	0.14
1994	1	1	5.7	0.7	4.5	3.3	3.6	2.3	159.8	23.8	3.2	1.7	39.8	21.4	2,843	122.4	0.56	0.26	0.28	0.08
	1	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.56	0.34	0.34	0.10
	1	26	5.3	1.1	4.8	3.9	4.2	3.2	160.4	17.7	15.2	9.7	74.3	23.8	3,177	285.5	0.36	0.21	0.27	0.09
1995	1	1	8.7	2.7	3.0	1.5	2.0	1.1	168.3	21.6	9.5	14.1	65.9	22.1	1,873	735.0	3.92	2.44	1.13	0.62
	1	17	8.1	2.0	1.9	1.1	1.1	0.4	186.8	47.1	34.7	44.3	45.1	35.0	2,046	618.4	3.13	1.75	1.10	0.54
	2	1	7.4	2.1	2.1	1.2	1.7	1.0	168.7	31.0	9.4	14.0	54.4	33.2	1,942	753.9	4.20	2.90	1.05	0.65
	2	11	7.2	1.7	2.2	2.0	1.6	1.1	157.0	26.0	16.4	17.4	51.9	34.1	2,143	805.6	3.27	2.18	1.05	0.62
1996	1	1	9.2	2.6	3.4	0.7	2.8	0.3	161.4	34.0	17.5	13.9	39.6	29.2	2,465	297.2	2.39	1.16	0.82	0.38
	1	18	8.2	2.7	2.4	0.7	2.2	0.3	161.4	56.5	36.3	37.6	50.9	27.8	2,663	176.1	1.40	0.56	0.81	0.37
	2	1	8.8	2.6	2.7	0.8	2.2	0.4	160.3	37.3	8.2	14.6	40.7	25.9	2,466	275.0	1.77	0.50	0.85	0.36
	2	11	8.4	2.8	3.4	1.6	2.9	1.3	147.2	41.3	28.7	24.5	49.7	25.9	2,630	220.7	1.07	0.29	0.77	0.31
1997	1	1	7.3	1.9	2.7	1.0	2.6	0.9	155.2	33.9	14.0	14.2	21.9	23.9	2,347	354.4	2.56	1.42	1.51	0.66
	1	18	7.2	1.5	2.6	0.5	2.3	0.4	193.7	68.6	63.6	53.3	55.3	14.5	2,995	503.5	1.12	0.50	1.08	0.38
	2	1	6.9	1.7	3.6	1.8	3.1	1.5	155.8	37.8	13.3	15.8	16.9	21.8	2,435	351.3	1.68	1.25	1.19	0.83
	2	13	6.5	1.4	2.8	1.9	2.3	0.8	148.1	38.7	20.9	12.4	29.6	20.1	2,584	433.5	1.33	1.17	1.06	0.76

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	Station	Depth	Total Phosphorus		Total filterable-P		Filterable reactive-P		Total Kjeldahl Nitrogen		Ammonia		Nitrate +Nitrite		Reactive Silicon		Chlorophyll *a*		Phaeophytin *a*	
Year		(m)	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD	(µg/L)	SD
1998	1	1	9.0	1.7	3.3	0.8	1.9	0.0	192.9	7.7	21.2	13.9	38.1	15.9	2,387	73.0	0.10	0.04	0.04	0.02
	1	18	7.5	ND	3.7	ND	1.9	ND	182.2	ND	24.5	ND	62.6	ND	2,311	ND	0.09	ND	0.03	ND
1999	1	1	17.7	18.3	8.6	10.2	6.8	10.0	246.9	147.2	35.7	42.6	123.9	35.2	2,390	431.5	2.94	3.19	0.56	0.35
2000	1	1	9.5	4.3	3.1	1.6	1.8	1.6	56.5	36.6	19.4	12.5	71.5	36.1	ND	ND	2.43	1.46	1.10	0.80
2001	1	1	7.8	5.1	6.4	5.2	8.2	6.7	114.5	22.2	4.6	3.6	37.9	32.5	ND	ND	2.37	0.53	0.30	0.20
2002	1	1	6.4	2.3	4.5	3.1	1.5	0.9	131.3	15.4	4.9	2.5	26.7	18.8	ND	ND	1.36	0.14	0.30	0.20
2003	1	1	6.5	3.0	2.2	0.8	2.1	0.8	ND	ND	5.7	1.8	54.4	26.9	ND	ND	1.20	0.20	0.50	0.40
2004	1	1	6.2	3.5	4.3	3.2	2.0	0.7	169.0	103.8	8.5	2.8	60.7	31.5	2,764	342.8	1.15	0.18	0.28	0.08
	1	18	5.9	2.3	6.2	8.3	3.5	3.5	ND	ND	19.0	13.2	79.8	28.4	2,914	277.1	0.70	0.35	0.19	0.11
2005	1	1	11.4	4.4	7.6	3.6	3.6	3.1	161.0	45.6	4.4	2.0	40.5	34.8	2,701	243.7	1.60	0.68	0.24	0.11
2006	1	1	7.2	4.3	2.2	1.6	2.3	1.1	97.0	59.6	7.1	1.7	28.0	30.8	ND	ND	1.92	0.32	0.50	0.09
2007	1	1	3.6	0.4	1.1	0.3	1.1	0.6	115.0	32.4	5.6	0.7	55.5	39.5	ND	ND	1.47	0.43	0.21	0.08
2008	1	1	3.8	1.1	2.3	1.5	1.6	0.9	112.8	28.6	5.9	0.6	65.0	42.3	ND	ND	1.22	0.66	0.58	0.37
2009	1	1	4.8	1.1	1.3	0.3	1.8	1.0	130.8	29.7	4.2	0.8	38.8	40.0	ND	ND	1.92	0.64	0.63	0.33
2010	1	1	4.4	0.8	2.5	0.4	1.7	0.3	19.0	15.7	4.3	0.8	22.5	32.1	2,363	682.2	1.12	0.16	0.63	0.25
2011	1	1	5.8	0.6	2.5	0.4	4.7	2.0	208.8	21.3	17.7	6.9	41.7	27.2	2,440	254.8	1.19	0.62	0.62	0.23
2012	1	1	3.8	0.2	1.7	0.2	0.8	0.3	298.7	59.3	5.8	3.6	33.5	36.0	2,806	235.5	1.74	0.59	0.12	0.06
2013	1	1	4.3	0.6	1.9	0.3	1.5	0.7	374.8	55.6	13.4	7.2	20.7	21.3	2,801	238.3	1.31	0.51	0.38	0.16
2014	1	1	3.8	0.6	1.2	0.4	1.2	0.7	524.0	381.6	6.0	6.1	13.5	18.4	2,312	509.8	1.68	0.50	0.34	0.30
2015	1	1	3.3	0.9	1.4	0.1	0.9	0.4	373.0	330.0	5.6	3.5	33.8	51.8	861	264.9	1.85	0.50	0.81	0.47
2016	1	1	4.4	0.8	1.8	0.3	1.4	0.2	1,063.5	710.2	8.1	3.9	29.5	21.6	2,045	303.5	1.92	0.29	0.95	0.41
Pre-fertilization yrs. (1987–1989)		1	8.0	2.6	4.4	1.8	2.5	0.5	132.6	14.0	3.6	2.8	78.5	43.5	2,766	321.2	1.10	0.61	0.59	0.21
Fertilization yrs. (1990–2000)		1	7.7	3.1	3.6	2.2	2.9	1.7	156.2	34.5	12.8	11.8	51.5	26.5	2,581	317.6	1.76	1.12	0.69	0.36
All yrs. (1987–2015)		1	6.6	2.5	3.3	1.8	2.5	1.3	167.1	51.6	8.6	6.4	48.2	30.7	2,461	315.1	1.52	0.72	0.54	0.27
Post-fertilization yrs. (2001–2015)		1	5.2	1.9	2.9	1.4	2.3	1.3	202.1	85.8	6.9	3.0	38.2	32.3	2,381	346.5	1.54	0.44	0.43	0.22
5-year (2011–2015)		1	4.2	0.6	1.7	0.3	1.8	0.8	355.9	169.6	9.7	5.5	28.6	30.9	2,244	300.7	1.55	0.54	0.45	0.24

Appendix A11.–Mean zooplankton density by species for station 1 and 2, Afognak Lake, 1987–2016.

		Density (no/m^2)						
Year	No. samples	*Epischura*	*Diaptomus*	*Cyclops*	*Bosmina*	*Daphnia*	*Holopedium*	Totals
1987	4	28,835	173	4,127	138,370	3,218	2,574	177,297
1988	8	16,508	20	1,997	107,650	1,184	1,085	128,444
1989	10	13,314	-	2,462	58,937	1,099	950	76,762
1990	14	13,994	4	6,724	141,664	2,871	4,485	169,741
1991	12	20,282	770	5,442	181,458	3,718	4,554	216,222
1992	14	16,208	315	3,122	94,856	4,017	2,443	120,959
1993	14	26,463	425	4,921	207,962	5,130	3,852	248,751
1994	16	17,360	1,314	6,484	191,551	6,971	4,870	228,548
1995	14	14,476	3,382	16,993	162,147	11,321	1,281	209,599
1996	10	31,502	223	7,272	285,276	10,202	2,240	336,715
1997	12	14,022	4,494	14,194	83,825	10,686	919	128,140
1998	4	15,672	1,088	2,070	169,971	10,881	5,441	205,123
1999	4	18,737	5,945	6,688	133,175	9,449	2,495	176,489
2000	5	57,643	8,121	10,743	114,297	5,042	1,408	197,254
2001	5	30,122	2,548	8,121	40,764	1,253	2,638	85,446
2002	4	8,174	1,009	6,380	38,256	2,935	557	57,311
2003	4	39,743	3,782	3,185	102,110	1,393	1,194	151,407
2004	10	25,199	271	5,750	46,721	6,830	2,198	86,967
2005	10	21,826	796	5,544	66,201	2,897	1,464	98,727
2006	10	19,487	1,980	6,499	60,400	5,990	3,811	98,166
2007	10	13,591	2,036	7,206	65,661	2,160	1,890	92,543
2008	10	18,674	1,208	2,577	58,011	2,509	2,197	85,174
2009	10	9,276	53	1,527	23,864	2,123	1,055	37,898
2010	10	9,557	106	746	45,242	759	1,415	57,824
2011	10	14,438	1,964	3,907	49,050	762	2,282	72,402
2012	10	16,157	1,062	2,909	46,757	2,527	1,030	70,441
2013	10	10,361	53	3,360	45,900	4,217	2,028	65,919
2014	10	16,561	452	1,699	73,912	6,476	1,168	100,267
2015	10	28,769	1,232	3,896	73,907	1,258	3,212	112,272
2016	10	31,668	849	3,291	94,586	4,565	5,813	140,791
Pre-fertilization yrs. (1987–1989)	7	19,552	64	2,862	101,652	1,834	1,536	127,501
Fertilization yrs. (1990–2000)	11	22,396	2,371	7,696	160,562	7,299	3,090	203,413
All yrs. (1987–2015)	9	20,240	1,546	5,398	100,272	4,478	2,301	134,235
Post-fertilization yrs. (2001–2015)	9	20,240	1,237	4,220	55,784	2,939	1,876	84,851
5 yr. (2011–2015)	10	17,257	952	3,154	57,905	3,048	1,944	84,260

Note: Data from station 1 only, 1998–2003.

Appendix A12.–Mean zooplankton biomass by species for station 1 and 2, Afognak Lake, 1988–2016.

		Biomass (mg/m^2)						
Year	No. Samples	*Epischura*	*Diaptomus*	*Cyclops*	*Bosmina*	*Daphnia*	*Holopedium*	TOTALS
1987	4	100	1	6	134	4	6	251
1988	8	61	0	3	107	3	3	177
1989	10	53	-	4	50	2	2	110
1990	14	54	-	11	121	5	8	198
1991	12	91	3	10	163	8	9	283
1992	14	69	1	5	96	9	5	185
1993	14	99	1	8	202	10	8	326
1994	16	53	5	11	186	13	9	276
1995	14	64	10	25	148	17	2	265
1996	10	161	1	13	309	27	4	515
1997	12	63	9	23	65	15	1	175
1998	4	62	5	3	144	14	8	236
1999	4	78	24	12	130	20	5	269
2000	5	180	44	16	126	9	2	377
2001	5	66	6	10	33	1	4	120
2002	4	21	3	7	36	3	1	71
2003	4	73	7	4	85	2	2	173
2004	10	40	1	8	39	10	4	102
2005	10	59	2	7	51	4	2	126
2006	10	53	5	13	46	8	7	132
2007	10	44	6	12	57	3	4	126
2008	10	48	5	3	47	4	4	111
2009	10	27	0	2	17	3	2	50
2010	10	27	0	1	32	1	2	64
2011	10	39	3	6	33	1	4	87
2012	10	56	3	4	36	4	2	105
2013	10	26	0	5	34	5	4	73
2014	10	66	2	4	55	8	3	136
2015	10	85	4	10	56	1	7	162
2016	10	74	3	7	69	6	11	169
Pre-fertilization yrs. (1987–1989)	7	71	0	4	97	3	4	179
Fertilization yrs. (1990–2000)	11	89	9	12	153	13	5	282
All yrs. (1987–2015)	9	66	5	8	91	7	4	182
Post-fertilization yrs. (2001–2015)	9	49	3	6	44	4	3	109
5 yr. (2011–2015)	10	54	2	6	43	4	43	113

Note: Data from station 1 only, 1998-2003.

Appendix A13.–Mean zooplankton size by species for station 1 and 2, Afognak Lake, 1988–2016.

		Size (mm)					
Year	No. Samples	*Epischura*	*Diaptomus*	*Cyclops*	*Bosmina*	*Daphnia*	*Holopedium*
1987	4	0.91	1.01	0.65	0.33	0.54	0.52
1988	8	0.95	1.44	0.70	0.33	0.68	0.54
1989	10	0.95	-	0.66	0.31	0.64	0.47
1990	14	0.95	0.90	0.67	0.31	0.63	0.47
1991	12	1.00	0.84	0.74	0.32	0.69	0.50
1992	14	0.97	0.94	0.68	0.33	0.72	0.45
1993	14	0.94	0.76	0.67	0.33	0.67	0.49
1994	16	0.89	0.95	0.67	0.33	0.65	0.47
1995	14	0.98	0.91	0.65	0.32	0.60	0.43
1996	10	1.04	0.83	0.73	0.35	0.77	0.47
1997	12	1.00	0.75	0.66	0.29	0.57	0.42
1998	4	0.96	1.05	0.67	0.31	0.56	0.42
1999	4	0.97	0.97	0.71	0.33	0.68	0.46
2000	5	0.88	1.09	0.66	0.35	0.64	0.46
2001	5	0.77	0.79	0.61	0.30	0.49	0.43
2002	4	0.82	0.92	0.56	0.32	0.51	0.41
2003	4	0.73	0.74	0.62	0.30	0.60	0.48
2004	10	0.70	0.91	0.64	0.30	0.60	0.46
2005	10	0.84	0.83	0.62	0.30	0.65	0.41
2006	10	0.78	0.82	0.73	0.29	0.58	0.45
2007	10	0.87	0.91	0.71	0.31	0.57	0.49
2008	10	0.83	0.94	0.60	0.30	0.65	0.47
2009	10	0.83	0.70	0.62	0.28	0.53	0.46
2010	10	0.78	0.82	0.57	0.28	0.59	0.45
2011	10	0.82	0.66	0.66	0.28	0.58	0.48
2012	10	0.94	0.81	0.64	0.30	0.61	0.51
2013	10	0.79	0.91	0.65	0.29	0.56	0.46
2014	10	0.92	0.97	0.79	0.28	0.51	0.51
2015	10	0.86	0.85	0.77	0.29	0.45	0.48
2016	10	0.79	1.01	0.79	0.29	0.56	0.56
Pre-fertilization yrs. (1987–1989)	7	0.93	0.82	0.67	0.32	0.62	0.51
Fertilization yrs. (1990–2000)	11	0.96	0.91	0.68	0.32	0.65	0.46
All yrs. (1987–2015)	9	0.88	0.86	0.66	0.31	0.60	0.46
Post-fertilization yrs. (2001–2015)	9	0.82	0.84	0.65	0.29	0.56	0.46
5 yr. (2011–2015)	10	0.87	0.84	0.70	0.29	0.54	0.49

Note: Data from station 1 only, 1998–2003.

Appendix A14.–Sockeye salmon escapement and adult returns by age for Afognak Lake, 1982–2016.

Brood year	Escapement	Age class returns 0.1	0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	4.1	2.4	3.3	Total return	R/S
1982	123,055	2	0	17	112	5,504	112	0	13,845	762	0	0	371	0	0	0	0	20,726	0.17
1983	40,049	0	0	337	0	9,828	297	0	10,013	4,627	0	0	1,707	0	0	35	0	26,844	0.67
1984	94,463	0	0	1,588	54	24,634	1,307	0	47,110	22,360	0	339	24,078	0	0	0	0	121,471	1.29
1985	53,872	36	96	272	0	10,583	2,902	0	26,542	10,030	0	0	6,568	0	0	65	0	57,094	1.06
1986	48,333	0	0	8,022	35	54,737	717	0	108,494	4,958	0	428	10,370	0	0	0	0	187,760	3.88
1987	26,474	0	0	773	0	20,889	313	0	25,139	3,198	99	0	9,772	177	0	0	0	60,359	2.28
1988	39,012	0	0	472	0	18,628	8,360	0	23,626	9,607	57	77	9,686	80	0	0	0	70,593	1.81
1989	88,825	0	0	17,807	0	8,321	13,427	0	35,677	10,450	157	253	13,374	0	0	397	0	99,863	1.12
1990	90,666	0	0	12,902	0	30,978	4,194	0	96,927	18,526	0	397	56,869	175	0	0	199	221,167	2.44
1991	86,481	0	280	9,681	277	37,463	1,440	0	96,284	4,507	0	48	22,573	0	0	0	0	172,552	2.00
1992	75,370	0	0	3,925	175	20,223	4,698	0	70,857	3,087	0	365	5,377	0	0	0	0	108,706	1.44
1993	69,291	0	0	35,159	0	40,046	10,200	0	47,921	10,364	222	330	8,915	646	0	0	680	154,484	2.23
1994	79,380	0	0	7,863	0	7,842	6,959	74	12,841	57,821	74	0	52,384	2,531	0	0	205	148,593	1.87
1995	98,691	0	0	18,569	0	52,527	718	0	11,888	4,523	0	0	11,396	0	75	0	0	99,696	1.01
1996	100,018	0	0	1,463	0	1,888	264	0	6,789	925	4,213	0	996	6,818	0	0	3,992	27,348	0.27
1997	130,450	0	30	1,571	0	3,202	1,787	0	6,775	5,147	171	0	8,408	787	0	186	875	28,938	0.22
1998	65,809	0	0	399	0	207	666	0	238	7,296	0	3	4,225	0	0	0	0	13,033	0.20
1999	94,011	0	0	20	0	6,409	67	0	2,996	291	0	0	293	0	0	0	0	10,076	0.11
2000	54,644	0	0	1,173	0	6,971	26	0	18,560	495	0	36	2,199	0	0	0	0	29,460	0.54
2001	23,981	0	0	177	164	2,258	142	0	5,176	608	0	8	1,202	0	0	0	0	9,735	0.41
2002	19,340	0	0	716	20	14,769	0	0	11,665	435	0	1	196	0	0	0	0	27,803	1.44
2003	27,498	0	0	580	0	7,074	71	0	14,358	1,054	0	1	890	0	0	0	0	24,028	0.87
2004	15,181	0	0	1,105	0	11,631	90	0	15,538	710	0	64	140	0	0	0	0	29,278	1.93
2005	20,281	0	0	1,238	0	13,151	911	0	51,698	328	0	200	9,530	0	0	0	0	77,056	3.80
2006	21,488	0	0	1,492	0	10,108	127	0	18,494	5,727	0	54	4,876	0	0	0	0	40,878	1.90
2007	20,033	0	0	1,691	0	26,090	2,119	0	26,626	6,553	0	20	5,549	0	0	0	0	68,648	3.43
2008	26,052	0	0	2,753	0	7,379	367	0	31,931	2,570	0	0	4,873	0	0	0	0	49,873	1.91
2009	30,818	0	0	1,094	0	9,801	0	0	16,230	5,203	0	0	5,839	0	0	0	0	38,167	1.24
2010	51,821	0	0	92	0	8,365	245	0	17,474	1,764	0	26	5,892	0	0				
2011	48,588	0	0	1,373	0	11,464	521	0	19,098	3,627									
2012	41,046	0	0	1,089	72	3,835	0												
2013	40,888	0	0	616															
2014	35,704	0																	
2015	36,780																		
2016	32,459																		
Pre-fertilization yrs. (1982–1989)	64,260	5	12	3,661	25	19,141	3,429	0	36,306	8,249	39	137	9,491	32	0	62	0	80,589	1.54
Fertilization yrs. (1990–2000)	85,892	0	28	8,430	41	18,887	2,820	7	33,825	10,271	425	107	15,785	996	7	17	541	92,187	1.12
All yrs. (1982–2009)	59,413	1	15	4,745	30	16,541	2,224	3	30,508	7,220	178	94	10,095	400	3	24	212	72,294	1.48
Post-fertilization yrs. (2001–2009)	22,741	0	0	1,205	21	11,362	425	0	21,302	2,576	0	39	3,677	0	0	0	0	40,607	1.88

Note: Escapement reflects egg take removals. Years after 2009 not fully recruited.

Appendix A15.–Number and percentage of sockeye salmon escapement into Afognak Lake, by year, and ocean age, 2000–2016.

	Ocean age								
Year	1	%	2	%	3	%	4	%	Total fish
2000	1,361	2.5	6,404	11.8	46,300	85.6	0	0.0	54,064
2001	5,443	22.4	3,490	14.4	15,338	63.2	0	0.0	24,271
2002	804	4.1	11,423	58.5	7,293	37.4	0	0.0	19,520
2003	1,344	4.8	14,410	51.9	12,012	43.3	0	0.0	27,766
2004	194	1.3	7,206	47.5	7,618	50.2	163	1.1	15,181
2005	833	3.9	2,664	12.3	18,080	83.8	0	0.0	21,577
2006	550	2.4	15,234	66.4	7,109	31.0	41	0.2	22,933
2007	1,143	5.4	7,280	34.5	12,640	60.0	8	0.0	21,070
2008	1,252	4.7	12,181	45.3	13,442	50.0	0	0	26,874
2009	2,263	7.2	13,242	42.2	15,853	50.6	0	0	31,358
2010	1,480	2.8	8,501	16.3	42,222	80.8	52	0.1	52,255
2011	3,693	7.5	24,112	49.0	21,237	43.2	152	0.3	49,193
2012	1,294	3.1	12,331	29.7	27,881	67.1	48	0.1	41,553
2013	78	0.2	10,438	24.8	31,621	75.0	17	0.0	42,154
2014	1,618	4.5	13,623	37.5	21,104	58.1	0	0.0	36,345
2015	1,610	4.2	13,228	34.7	23,313	61.1	0	0.0	38,151
2016	616	1.9	7,463	22.5	25,062	75.6	26	0.1	33,167
Average (2000–2015)	1,560	5.1	10,985	36.1	20,191	58.8	30	0.1	32,767
Average (2011–2015)	1,658	3.9	14,746	35.1	25,031	60.9	43	0.1	41,479

Appendix A16.–Relative yearly phytoplankton and mean biovolume in Afognak Lake, by phylum, 2010–2016.

	Biovolumes (µm^3/L)							
Phylum - Algal group	2010	2011	2012	2013	2014	2015	2016	Mean
Bacillariophyta (Diatoms)	4,740,446	228,802	728,394	117,045,785	173,028,927	162,370,768	172,762,113	90,129,319
	16.7%	34.9%	66.8%	49.5%	53.3%	42.2%	28.8%	40.0%
Chlorophyta (Green algae)	130,541	17,375	0	12,639,969	24,359,942	21,144,413	138,809,642	28,157,412
	0.5%	2.7%	-	5.3%	7.5%	5.5%	23.2%	12.5%
Chrysophyta (Golden-brown algae)	2,265,299	267,446	0	85,184,272	19,690,417	27,488,943	71,053,488	29,421,409
	8.0%	40.8%	-	36.0%	6.1%	7.1%	11.9%	13.1%
Cryptophyta (Cryptomonads)	2,682,616	40,010	134,374	13,003,103	21,991,389	49,237,017	104,353,941	27,348,921
	9.5%	6.1%	12.3%	5.5%	6.8%	12.8%	17.4%	12.2%
Cyanophyta (Blue-green algae)	210,536	50,280	18,027	2,393,609	3,364,528	5,323,974	30,910,741	6,038,814
	0.7%	7.7%	1.7%	1.0%	1.0%	1.4%	5.2%	2.7%
Euglenophyta	0	0	0	0	0	0	9,118,774	1,302,682
	-	-	-	-	-	-	1.5%	0.6%
Haptophyta	29,984	8,767	0	0	0	0	0	5,536
	0.1%	1.3%	-	-	-	-	-	0.0%
Pyrrhophyta (Dinoflagellates)	18,313,380	42,107	209,872	6,260,603	82,351,757	119,033,390	72,494,149	42,672,180
	64.5%	6.4%	19.2%	2.6%	25.4%	31.0%	12.1%	19.0%
Totals	28,372,803	654,787	1,090,666	236,527,341	324,786,960	384,598,505	599,502,848	225,076,273